AEROSPACE REPORT No.
ATR-77(7921)-2, Vol. I

EQUIPMENT SYSTEMS IMPROVEMENT PROGRAM

BODY ARMOR FIELD TEST AND EVALUATION FINAL REPORT

Volume I - Executive Summary

Law Enforcement and Telecommunications Division
September 1977

DEVELOPMENT

Prepared for

lational Institute of Law Enforcement and Criminal Justice
LAW ENFORCEMENT ASSISTANCE ADMINISTRATION
U.S. DEPARTMENT OF JUSTICE

The Aerospace Corporation

Aerospace Report No.
ATR-77(7921)-2, Vol. I

EQUIPMENT SYSTEMS IMPROVEMENT PROGRAM

FINAL REPORT

BODY ARMOR FIELD TEST AND EVALUATION

VOLUME I - EXECUTIVE SUMMARY

Law Enforcement and Telecommunications Division
THE AEROSPACE CORPORATION
Washington, D. C.

September 1977

Prepared for

National Institute of Law Enforcement
and Criminal Justice

LAW ENFORCEMENT ASSISTANCE ADMINISTRATION
U. S. DEPARTMENT OF JUSTICE

Contract No. J-LEAA-025-73

This project was supported by Contract Number J-LEAA-025-73 awarded by the Law Enforcement Assistance Administration, U. S. Department of Justice, under the Omnibus Crime Control and Safe Streets Act of 1968, as amended. Points of view or opinions in this document are those of the authors and do not necessarily represent the official position or policies of the U. S. Department of Justice.

Aerospace Report No.
ATR-77(7921)-2, Vol. I

EQUIPMENT SYSTEMS IMPROVEMENT PROGRAM

FINAL REPORT

BODY ARMOR FIELD TEST AND EVALUATION

VOLUME I - EXECUTIVE SUMMARY

Approved:

Joseph Meltzer, General Manager
Law Enforcement and Telecommunications
Division

ABSTRACT

This three volume report examines the acceptability and performance of various designs of soft body armor, all utilizing Kevlar 29 as the principal ballistic material. The effects of fit, comfort, and heat containment on garment acceptance and wear are assessed. Those factors most important in the use and specification of armor are identified.

Based upon confiscated weapon statistics, FBI assault data, and the wear histories of the garments tested, it is found that armor containing 7 to 12 plies of protective material is optimum in terms the likelihood of preventing fatalities or injuries. Changes in attitudes of the officers wearing armor was found to be negligible. None of the armor designs tested interfered with the officers' activities, and in no case did internal injuries result.

An area meriting further investigation is the study of blunt trauma from higher energy threats, in particular the .357 magnum and 9mm handguns.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (continued)

ACKNOWLEDGMENTS

The Lightweight Body Armor Program required the support and participation of many organizations and people.

The National Institute of Law Enforcement and Criminal Justice, Law Enforcement Assistance Administration provided not only the financial support of the program but also management, support, and direction. The 15 participating police departments, their Chiefs and senior staff personnel supported the program and its execution. The test conductors in each department coordinated the program and handled the data forms. Without the cooperation of the 6000 officers who participated in the field test, there could have been no program.

The trauma surgeons in each of the test cities gave of their time and effort to become familiar with the program and to assist in evaluating the incidents which occurred.

The U.S. Army, Edgewood Arsenal investigated the higher energy threats, supported the law enforcement community and manufacturers in evaluating protective garments, established the treatment/diagnostic protocol, and determined the medical implications of assaults involving protective garments. The U.S. Army, Natick Laboratories provided improved garment design and maintenance data. Also, the Natick Laboratories and the U.S. Army Research Institute of Environmental Medicine quantified the human factors aspects of the new design garments.

The National Bureau of Standards, Law Enforcement Standards Laboratory, the Personal Protective Armor Association, and the International Asso Association of Chiefs of Police, Equipment Technology Center were responsible for the development and implementation of test standards and for tests of commercial armor. The armor manufacturing industry assisted in the collection of incident data.

The Secret Service provided continued participation in and support of the total program. The Federal Bureau of Investigation made available statistical data support from their Uniform Crime Reports Section and the Academy Instructors at Quantico supported the human factors test program.

PREFACE

It is the purpose of this final report to present a comprehensive review of the field test and evaluation of the soft body armor that was developed and designed for the National Institute of Law Enforcement and Criminal Justice (NILECJ), the Law Enforcement Assistance Administration (LEAA), and commercial body armor that was designed of identical ballistic material. During 1976, approximately 5000 garments were issued to patrol officers in 15 cities. The statistical analysis and evaluation of the test data were completed in August 1977, supported by a subcontract to the Laboratory for Statistical and Policy Research of Boston College.

As a result of the field test and evaluation, various design modifications of the LEAA armor were implemented and tested. Studies to characterize the mechanical and ballistic properties of Kevlar 29 (the ballistic material common to all modern soft armor and that used in the field test) from a theoretical point of view were conducted. Finally, guidelines for the specification and procurement of armor were developed. This report also provides a comprehensive review of these activities.

This report is presented in three volumes. Volume I - Executive Summary presents an overview of the field test and evaluation activities, the findings, and the principal conclusions and recommendations. Volume II - Test and Evaluation presents a comprehensive discussion of all tests, studies, analyses, and evaluations. In addition, details are given of the test design and analytical approach, as well as a summary of three Medical-Technical Symposia held during the program, reports on all incidents, or shootings, involving armor, and the technology transfer activities carried out at the end of the program. Volume III - Appendices includes the questionnaires used to generate the data, a model procurement document and data on later studies. The raw data used for statistical analyses are not included in Volume III because of their sheer bulk; they are, however, available to interested parties. These volumes represent a follow-on to previous reports covering the design and development and pilot test phases of the Body Armor Program.

The content of the Executive Summary, Volume I, is an abbreviated version of the Test and Evaluation, Volume II, but is structured to stand alone. For convenience, the following clarifies the content of each Section:

- Section I contains a brief description of the garment development phase of the program and defines the rationale and methods of conducting the field test.

- Section II provides a narrative description of nine assaults which occurred during the test program directed against officers who were issued LEAA 7-ply garments.

- Section III presents a summary of the results of the statistical analysis of the test data and measures the degree to which the goals and objectives of the program were met.

- Section IV summarizes the results of parallel research conducted on new materials and garment designs that were based on the initial findings of the field test. This effort is the feedback phase of the test program.

- Section V highlights the more important considerations for the use and procurement of soft armor.

- Section VI presents a summary of research on the fundamental ballistic characteristics of Kevlar fabric.

- Section VII reports on the findings of the field test in accordance with the goals of the program as originally defined in the test plan published in June 1975. Additionally, because of their importance, the recommendations are carried forward from Volume II in their entirety.

CHAPTER I. INTRODUCTION

In the years preceding 1973, the substantial increase in the fatality rate of law enforcement officers plus the assassination attempts on such key figures as Senator Stennis and Governor Wallace emphasized the need for protection against the common handgun. The need was for a garment or armor system which would be lightweight and inconspicuous when worn as part of the uniform of an officer or business attire of a public official. Continuous wear capability was mandated as part of the program.

To meet this need, the National Institute of Law Enforcement and Criminal Justice (NILECJ), the research arm of the Law Enforcement Assistance Administration (LEAA), initiated in 1973 a program to develop and test lightweight body armor for law enforcement officers and public officials. Existing armors which were available to the law enforcement community used ballistic nylon, metal inserts, ceramics, or laminated fiberglass. For the most part, these armors were used for special situations in which a known threat had been identifed. They were generally heavy, hot, and highly conspicuous. As part of the Equipment System Improvement Program, LEAA undertook an investigation to develop an armor which could be worn continuously. Within these broad guidelines, LEAA assembled the technical support necessary to implement a program to develop lightweight body armor. The overall objectives established for the program were to:

- develop comfortable, inconspicuous, lightweight protective garments capable of providing protection against common handguns;
- demonstrate adequate user protection and acceptance via pilot test and field test; and
- disseminate the technology acquired to both users and industry.

Based on these objectives, the program effort was structured into four phases: feasibility assessment, garment development and pilot test, field test and technology transfer. This document provides a summary of the results obtained from the field test and technology transfer phases. The reports on the feasibility assessment and garment development and pilot test are referenced in the Bibliography, Section VIII. In addition, a brief discussion of the garment development work is presented below as background and for ease of reference.

A. Garment Development

A strong team of government and industrial organizations with the wide range of needed capabilities was assembled under the financial and program management direction of the Advanced Technology Division within the National Institute of Law Enforcement and Criminal Justice. The Aerospace Corporation was assigned the role of technical manager and test conductor and participated in the analyses and testing for the selection of yarn and fabric weaves. The U.S. Army, Edgewood Arsenal was assigned the responsibility for ballistic testing and assessing the medical aspects of the bullet/armor/body interactions. The U.S. Army, Natick Laboratories was given the responsibility to perform garment design and fabrication studies. The Mitre Corporation was responsible for establishing design and operational requirements for the armor system. The National Bureau of Standards, Law Enforcement Standards Laboratory, was charged with limited fabric testing and the development of guidelines and standards for the industry, based on the findings of the program. Industrial representatives from duPont provided consulting services on the Kevlar* yarn. Fabric weavers provided experimental runs of fabric woven from different yarns with different weave characteristics. Law enforcement agencies provided definitions of the threat data, guidance on the operational aspects of law enforcement agencies, and assessments of various garment types in terms of acceptability

*Registered trademark of E.I. duPont.

to the department and individual officers. The Lawrence Livermore Laboratory performed a series of ballistic tests designed to investigate the interaction of projectiles and the woven fabric.

In the first phase of the program, feasibility assessment, the operational requirements for soft body armor were established. The statistics on injurious and fatal assaults against law enforcement officers were analyzed to determine the characteristics and morphology of these assaults. In particular, these data were analyzed in conjunction with data on the distribution of confiscated weapons to assess the most likely threats. It was concluded that optimum protection would result from armor designed to protect the upper torso against the common handgun as characterized by the .38 caliber special with standard velocity ammunition. The feasibility assessment also included tests and analyses of candidate materials that resulted in the selection of Kevlar 29 as the superior ballistic resistant material. Indeed, early in the development program, the armor industry switched over to the almost exclusive use of Kevlar as the protective constituent of garments. This partially achieved one major objective of the program--technology transfer to industry. It also permitted the subsequent field test to include, for comparison, a wide variety of garment designs tailored to defeat ballistic threats higher than the design requirements.

Early in the development phase, extensive research was conducted on the two roles armor must fulfill--that of defeating penetration and that of limiting blunt trauma to the tissue and vital organs of the wearer. The objective of this development was to combine the analytical and experimental procedures with the physical and medical research in order to better understand the processes involved in protecting the wearer.

This part of the development phase resulted in the specification of 7 plies of Kevlar 29, 1000 denier, and 31 threads per inch in both warp and fill as being required to defeat the common handgun. The subsequent efforts were devoted to the human factors associated with garment design (e.g., form, fit, comfort). The design was required to meet the following operational requirements. The garments must:

- o be inconspicuous;
- o not hinder the wearer in the performance of his duties;
- o be resistant to deterioration and environmental effects; and
- o not hinder self defense by the wearer.

Seventy-five prototype garments designed to meet these requirements were fabricated for pilot testing in four cities for six months (including the summer months of 1974). Based on these tests, two styles of undershirts were selected, procured for the field test, and evaluated for acceptance and performance, which is the subject of the remainder of this document.

B. Test Implementation

The planning for the formal field test and evaluation was begun in 1974 and culminated with the publication of a test plan (i.e., Body Armor Field Evaluation Test and Evaluation Plan, Aerospace Report ATR-75(7921)-1, June 1975). The four major goals established for the test activity were to:

- o evaluate the acceptability to law enforcement agencies and personnel of inconspicuous, limited protection, continuous-wear, lightweight body armor;
- o evaluate the impact of this lightweight body armor on law enforcement operations;
- o evaluate garment performance (i.e., wearability, comfort, protective features, and impact of environmental factors); and
- o obtain data regarding the manufacture of these garments in a commercial environment.

These goals indicated the direction to be taken in the field evaluation tests. A widespread distribution of the test garments and commercial garments to law enforcement personnel throughout the nation was required to minimize bias due to regional, departmental, or officer attitudes and to evaluate the concept of continuous wear under a variety of seasonal and climatic conditions. In addition, methods of measuring the degree to which the test goals were met had to be devised. This was developed by relating a series of objectives to each goal which could be measured by questions to be asked of each test participant. The resultant evaluation matrix, shown in Table I-1, was used to devise a series of questionnaires that could be quantified and interpreted with standard statistical methods. Five questionnaires were developed for this purpose and directed at two groups of participants--a test group of volunteers to wear the garments and a control group not issued garments to be used as a reference for detecting any change in attitudes or performance. Two questionnaires, a pretest and posttest, were distributed to each member of the test and control groups. These were used to measure any changes between groups and any changes within a group before and after the test. The fifth questionnaire was issued each month during the test to members of the test group to detect any changes in parameter values as a function of time. The questionnaires are included as Appendix A to Volume III of this report. The last goal was measured in terms of procurement data obtained from subcontractors and from the armor industry.

The design of the evaluation matrix and questionnaires were the first steps of test implementation. The remaining steps involved test site selection, garment selection, and test operations.

1. Test site selection. In structuring the test program, it was desirable to provide protective garments to those law enforcement personnel exposed to the highest risk. FBI data from 1969 to 1973 indicate that the FBI

Table I-1. Test Definitions

Goals	Objectives	Measurement Questions	Population
Evaluate acceptability of continuous-wear-limited protection garments	Determine attitude of the individual officers to the protective garments	Does the garment afford an adequate level of protection? How does the officer feel while wearing the protective garment while interacting with the public? How does the officer feel toward his peers while wearing the vest?	Aggregate Individual cities Individual functions
	Determine acceptability by the individual officer to the protective garments	What is the frequency of wear of the garments? Does the garment fit? Is the appearance acceptable? Is the garment comfortable? Is there a correlation between acceptance wear and other parameters such as risk? What other factors influence user acceptance?	Aggregate Individual cities Individual functions
	Determine acceptability by the departments of the protective garments	Do the departments strongly support the test program? Are any unreasonable limitations imposed on the wearing of the garments? Is the department contemplating the purchase of protective garments?	Aggregate of cities or city pairs Individual cities
Evaluate impact of garments on law enforcement operations	Obtain data on the physchological change of officers while wearing protective garments	Do the officers become more aggressive while wearing protective garment garments? Does the officer's attitude toward the general public change due to wearing protective garments? What is the officer's attitude toward his fellow officers while wearing protective garments?	Aggregate of officers Individual cities Individual functions
	Obtain data on the physiological effect on officers while wearing protective garments	Does wearing the garment degrade the the officer's performance of his duties? Does wearing of garment increase the officer's fatigue? Have there been any instances of hyperventilation while wearing the garment garments?	Aggregate of officers Individual cities Individual functions
	Obtain data on the benefit of the protective garments to the individual and the department	Does the officer feel more secure while wearing the protective garments? What is the public reaction to the announcement of the cities participation in the test? What was the cost/benefit of the program?	Aggregate Individual cities functions Aggregate cities Individual cities City pairs Total number of incidents

Table I-1. Test Definitions (continued)

Goals	Objectives	Measurement Questions	Population
Evaluate garment performance	Obtain data on the inconspicuous appearance of the garments	Are the undergarments easily detectable by casual observers? Is Style I or Style II less conspicuous?	Aggregate Individual cities Individual functions
	Obtain data on the comfort of the garments	Does the garment fit? If not why? Is there adequate adjustment? Is it easy to put on and take off? Does it allow freedom of movement in ordinary duty wear? Is there significant hinderance during stress conditions, e.g., running, subduing adversary or weapon access? Are there any irritating features of the garment? Can it be worn continuously in both the summer and winter? Are there any limitations imposed upon the wearer by the garment?	Aggregate Individual cities Regional cities Individual functions Regional functions
	Obtain data on the wear degredation of the garments	Do the garments maintain their structural integrity? Does the ballistic material bunch? Does the material lose its structural integrity when used in the operational environment over a period of time? Does the material lose its ballistic resistant characteristics over a period of time?	Aggregate Individual cities Recalled garments
	Obtain data on the predicted protective features of the garments	Does the garment meet its operational requirements? What is the extent of the injury to an officer who has been hit in the area protected by the garment? Does the injury correlate with predicted data?	Incidents involving officers hit in the protected area

Group I cities (over 250,000 population) consistently exhibit the highest assault rates from firearms and cutting weapons. Data for the 58 Group I cities on assaults with injury to law enforcement personnel in 1971 and 1972 by firearms and cutting weapons were compared, and 16 candidate cities were identified as having both higher than average assault rates and available surgeons and facilities for the treatment of trauma. Initial contacts between the Institute and the individual cities indicated either an interest in participating in the field evaluation program or a desire for more information. During July and early August of 1974, visits were made to all 16 cities to provide briefings on the program, assess official reactions and interest in the program, and obtain additional agency data. Based on these visits, the subsequent data received, and geographic and climatic distribution, the following 15 cities were chosen for participation:

Albuquerque, New Mexico	Portland, Oregon
Atlanta, Georgia	Richmond, Virginia
Birmingham, Alabama	St. Louis, Missouri
Detroit, Michigan	St. Paul, Minnesota
Miami, Florida	Seattle, Washington
Newark, New Jersey	Tampa, Florida
New Orleans, Louisiana	Tucson, Arizona
Philadelphia, Pennsylvania	

2. Garment selection. The most important, and initial, factor that had to be determined for garment selection was the total number and styles to be distributed. Such decisions normally require tradeoffs to be made among time available, funds available, and program objectives. Thus, an analysis was made to determine the required number of officers to achieve three goals intimately related to the test size, viz: (a) demonstrate wearability,

(b) demonstrate capability of mass production of garments, and (c) demonstrate protection provided against handgun assaults. It was found that the third requirement was the overwhelming driving force and that 5000 man-years of garment wear would be required to obtain a high probability of four incidents on the general police population. A 1-year program to determine protective capability with an estimated 50 percent wear would require 10,000 garments and result in a costly program. A demonstration of wearability would require less than 2000 garments and mass production less than 1000 garments. Thus, steps were taken to reduce the size of the third requirement by placing garments in areas of maximum risk, i.e., in cities, units, and watches with the largest assault rates. The required number was thereby reduced to 5000 garments.

The styles of the garments were based on the development program prototype garments and the pilot wearability tests which indicated that the undervest was the most suitable style for routine wear by the patrol officer. Therefore, the majority of the garments issued, of both the LEAA and commercial designs were undervests. Because integrated garments were also well received, a limited number of these were also issued. Unfortunately, their use is limited by season, or climate. The mix of styles and quantities are shown in Table I-2.

3. Test operations. A memorandum of understanding was agreed upon by The Aerospace Corporation and the 15 participating cities that outlined their roles and responsibilities during the conduct of the program. Aerospace distributed the selected garments to a test conductor appointed by each participating police department. Training aids explaining the purpose and methods of testing, test plans, data forms, and medical forms were also distributed. The local police test conductor assigned garments to

Table I-2. Test Garments

Designation	Description	Quantity	Approximate Equivalent Plies
LEAA Style I	Full wraparound	1850	7
LEAA Style II	Contoured wraparound	1850	7
LEAA Style II	Contoured wraparound	300	10
Womens	Full wraparound	50 50	7 10
Integrated 1	Seattle north slope jacket	50	7
Integrated 2	St. Paul mackinaw	50	7
Integrated 3	Tucson jacket	50	7
Integrated 4	Detroit reefer coat	50	7
Integrated 5	Newark leather jacket	50	7
Style A	Commercial full wraparound	200	12
Style B	Commercial front and rear panels	200	14
Style C	Commercial front and rear panels	200	18
Style D	Commercial front and rear panels	200	24

participants and was responsible for the distribution, completion, and collection of questionnaires. Each garment was given an identification number that was correlated with a participant's questionnaire. All data were forwarded to Aerospace for processing. The test conductor was required to notify the local trauma surgeon and Aerospace immediately of any assaults against participants. In addition, the biomedical laboratories of the U.S. Army provided medical specialists to support the investigation and analysis of all medical data stemming from such incidents.

Finally, the Laboratory for Statistical and Policy Research of Boston College provided, under a subcontract, keypunch operations, data processing, and analysis of the large volume of data collected. All data were forwarded to Aerospace for collation and checking of the data forms and analysis of a 10-percent sample for validating results.

CHAPTER II. INCIDENT SUMMARIES

Prior to the start of the field test, it was estimated that 5000 garment-years of wear would prevent death or serious injuries to four or more officers from common handgun wounds in the upper torso area. During the course of the 1-year field program, six participating officers received ballistic wounds in the upper torso area, two were assaulted with knives, and one beaten with a cane. Figure II-1 shows five of the six ballistic incidents. In the figure, three of the officers were wearing the protective vest, and two of the officers had been issued vests but were not wearing them.

The photograph of the Seattle incident shows the two chest contusions resulting from .38 caliber handgun projectiles impacting a LEAA 7-ply vest. The range was point blank. In addition, this officer received a gun shot would in the left hand. Medical diagnosis through the use of x-ray, serial EKG, blood gas analysis, and cardiac monitoring indicated no internal damage due to the ballistic impacts. The surface contusions were abrasive in nature which wept some bloody fluid. A bruise and discoloration approximately 3 to 4 in. in diameter developed around each wound. The officer did not lose consciousness; he continued to struggle with his assailant.

The Richmond victim shows a chest contusion resulting from a .22 caliber handgun projectile at a range of 7 to 10 feet. Again the vest was a LEAA 7-ply garment. The 24-hour diagnostic observation again revealed no internal injuries as a result of the impact. The surface contusion, weeping of bloody fluid, and bruise were the only external evidence of the impact. This officer participated in the apprehension of his assailant immediately after receiving the wound.

The Portland incident shows an officer struck over the heart between the fifth and sixth ribs by a .22 caliber projectile fired by a carbine at a range

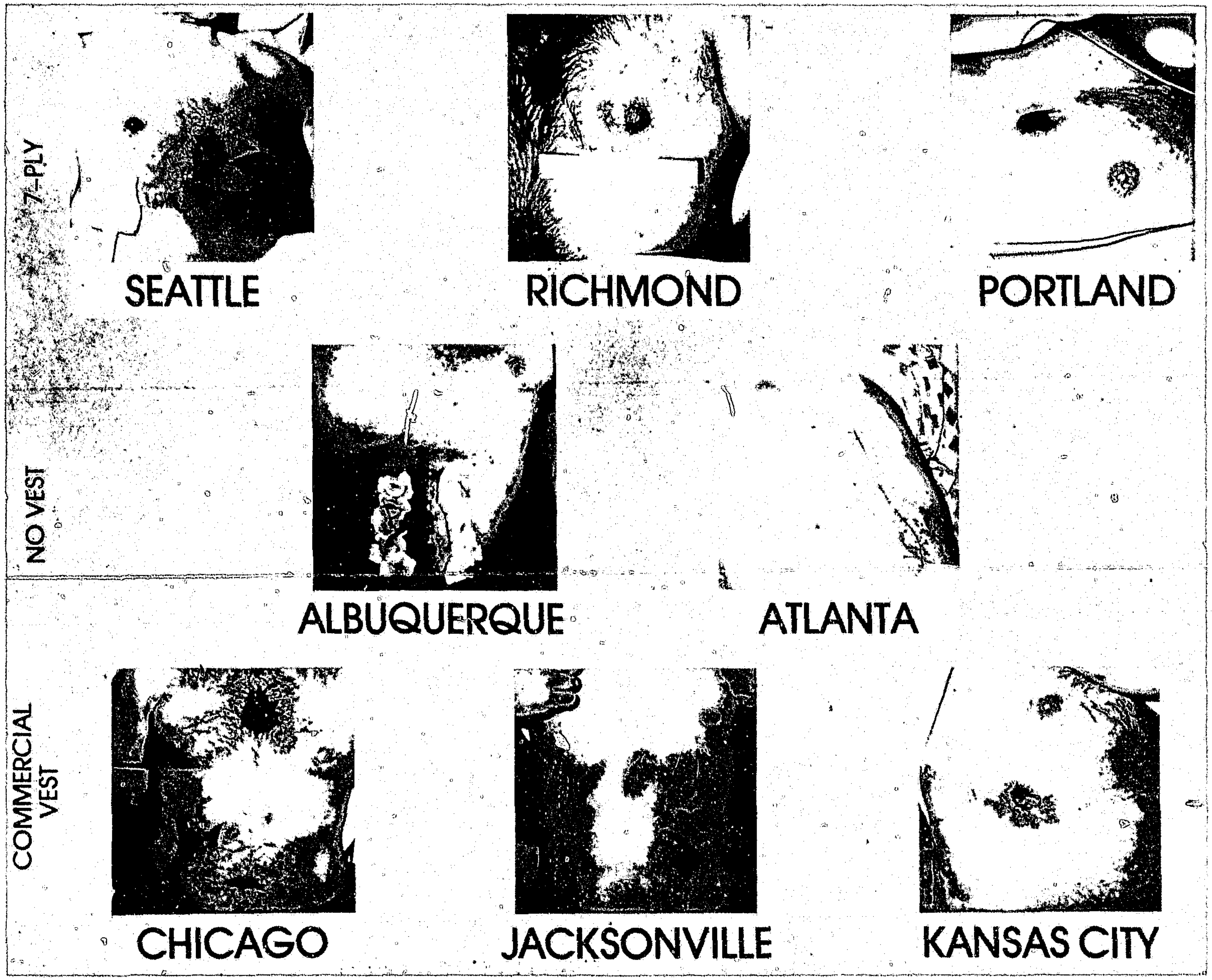

Figure II-1. Upper Torso Wounds of Participating Officers

of 150 yards. This officer was also wearing a 7-ply LEAA vest. In addition to the normal x-ray, EKG, and blood gas analysis, a radio isotope scan was made of the officer's heart. There was no evidence of any internal damage as a result of the impact. The surface contusion and slight swelling around the point of impact were the only external evidence of the ballistic impact. This officer was taken by surprise by the impact from an unknown direction without the opportunity to respond. Although the rated muzzle velocity of this rifle was 1260 feet per second (fps), penetration was limited to the outer ply of the vest; the victim received no internal injuries. The average velocity measured on a test range at 6 feet was 1247 feet per second. Since the range in the incident was approximately 150 yards, it was theorized by ballistic specialists that the impacting velocity was significantly less than rated muzzle velocity, and probably close to 1000 fps. Hence, it is highly probably that the ballistic impact equated reasonably with that of the .22 caliber handgun at close range.

Not shown in the photographs was an incident involving an officer wearing a program supplied commercial garment with front and back panel protection only. In addition to receiving approximately 50 revolver-fired No. 9 pellets in the left arm and head, he received a gun shot wound to the right side. The solid projectile missed the edge of the front of the vest, entered and exited the tissue on the right side, and nicked the edge of the rear of the vest. Although the officer did not sustain a serious wound, he could have escaped having any torso wound by side protection.

The photograph from Albuquerque shows the exploratory and repair incisions made on an officer struck four times in the upper torso.by .38 caliber handgun projectiles. This officer had received a program vest but was not wearing it. A postincident assessment indicated that three of the four perforations would have been prevented. The fourth which entered the shoulder area may not have been prevented since the entrance wound was located near where the edge of the ballistic resistant material would have been. The officer was scheduled to return to duty in October 1977, approximately 14 months after the incident.

The photograph of the Atlanta victim again shows the incision necessary to repair an abdominal gun shot wound. This officer had also received but was not wearing a program-provided vest. The projectile was from a .32 caliber revolver, and the entry wound was located in an area which would have been covered by the vest. After 9 months, the officer has not returned to duty. The projectile perforated the aorta, which may be causing circulation problems.

The last three photographs show the condition of the officers' torsos shot with .38 caliber handguns while wearing commercial garments designed for higher threat levels (i.e., containing up to 18 plies). Their surface injuries are similar to those shown in the first three photographs.

The two knife incidents occurred in the same city in the same unit. Both officers were disguised in a decoy unit when assaulted with knives in robbery attempts. Both officers received knife thrusts on LEAA 7-ply garments, and in neither case was there penetration of the garment. Both officers noticed a slight soreness at the point of impact which quickly disappeared.

In the cane incident, the officer was severely beaten by an assailant with a metal tipped cane in the back and rear rib area. The attending physician stated that there was a high probability that the garment prevented severe bruising and possibly cracked or broken ribs.

The medical data obtained from the program incidents and augmented by additional nonprogram garment incident data essentially validated the pretest predictions of the ballistic impact effects. The animal tests appear to give conservative results when compared to the human body response in terms of internal organ damage.

The Aerospace team and the U.S. Army Medical Team investigated a number of nonprogram incidents. Data were gathered on an additional number. A summary of all incident data is contained in Volume II of this report. The detailed medical data on each incident were collected by the U.S. Army Edgewood Arsenal Biomedical Group and may be published by Edgewood as a separate report.

CHAPTER III. STATISTICAL ANALYSIS

One of the major efforts in the test program was the data acquisition from the program participants in the form of a set of five questionnaires. The purpose of this data collection and analysis effort was to evaluate the acceptability, wearability, and impact on officers' attitudes as a result of wearing lightweight continuous wear protective garments. The quantity of data required computer processing of the information. This chapter contains a summary of the results of the data acquisition, processing, and evaluation efforts.

A. Principles of Analysis

The measurement goals and data collection procedures and the general statistical methodologies employed in analyzing the data for this study are discussed below.

The first goal concerned an evaluation of the acceptability of the lightweight protective garments worn by the officers during the test and a determination of the factors influencing the degree to which officers wore the garments. This evaluation included officers' perceptions of an adequate level of protection afforded by the garment, the degree to which the garment affected interactions with the public, and peer group approval. The frequency of garment wear, correlation of measured variables with garment wear, reasons for not wearing the garments, and reported causes for garment discomfort were factors which were analyzed in determining the degree of overall garment acceptability.

A second goal of the study was to ascertain the officers' impressions of the garment's performance. The performance of the garment was assessed with regard to the officers' interpretation of its inconspicuous appearance, comfort, the ability of the garment to maintain its original qualities during continuous use and after prolonged wear, and the ability of the garment to provide ballistic and blunt trauma protection.

An evaluation of the impact of the garment on law enforcement operations comprised the final goal of the study. Garment impact was measured in terms of whether it made for increased officer aggressiveness, whether it hindered an officer in the performance of his duties, and if the garment contributed to increased fatigue by officers while they were on duty. These goals and objectives are summarized in Table III-1.

Five questionnaires were developed to acquire the data needed to evaluate the measurement questions. The method of determining what effect the garment had on the officers was to compare the reactions of those who wore the garments (test group) with the reactions of officers who experienced the same conditions, but did not wear the garments (control group).

Prior to the initiation of the field tests when the garments were issued, questionnaires were completed by the test group and control group. The purpose of these questionnaires was to provide a data base on the demographic, attitudinal, and situational characteristics of the two groups. This was necessary in order for the differences between the two groups to be detected and accounted for when evaluating the attitudinal changes which occurred during the test period. Additionally, the data from these questionnaires were used to correlate attitude factors with garment acceptance.

Questionnaires were administered on a monthly basis to the test group only. The purposes of these questionnaires were to assess the frequency of garments wear, the problems created for the officers encountered by the garments, and the officers' attitudes toward the garments.

Questionnaires were administered to the test and control groups respectively at the completion of the 12-month field test. These questionnaires were designed both to detect, by comparison with the pretest questionnaire responses, attitudinal changes which occurred over the test period and to help assess the acceptability of the garments.

Table III-1. Field Test Goals and Objectives

Goals	Objectives	Questions
Evaluate acceptability of continuous wear limited protection garments.	Determine attitude of the individual officers toward the protective garments.	Do the garments afford an adequate level of protection? How does the officer feel while wearing the protective garment while interacting with the public? How does the officer feel toward his peers while wearing the vest?
	Determine acceptability by the individual officer to the protective garment.	What is the frequency of wear of the garments? What are the reasons the officer does not wear the garment? What are the major causes of garment discomfort and how severe is the discomfort?
Evaluate garment performance.	Obtain data on the inconspicuous appearance of the garments.	Are the undergarments easily detectable by casual observers? Is Style I or Style II less conspicuous?
	Obtain data on the comfort of the garments.	Do the garments fit? Is there adequate adjustment? Is it easy to put on and take off? Does it allow freedom of movement in ordinary duty? Does the garment comfort remain the same throughout a shift?
	Obtain data on the wear degradation of the garments.	Do the garments maintain their structural integrity? Does the ballistic material bunch?
Evaluate impact of garments on law enforcement operations.	Obtain data on the psychological change of officers while wearing protective garments.	Do the officers become more aggressive while wearing protective garments? Does wearing the garment degrade the officer's performance of his duties?
	Obtain data on the physiological effect on officers while wearing protective garments.	Does wearing the garment increase the officer's fatigue?

During the test, the test conductors in each city distributed and collected the completed questionnaires and forwarded them to Aerospace where a sample was selected. Aerospace in turn forwarded the complete set of questionnaires to the Laboratory for Statistical and Policy Research at Boston College, where they were visually validated for completeness and converted to machine-readable format for analysis

In addition to the questionnaire data, National Oceanic and Atmospheric Administration (NOAA) weather data were obtained for the cities involved in the study. The temperature and humidity of the environment in which the officers worked were hypothesized to affect the acceptance and use of the garment. For this purpose, the Temperature Humidity Index was calculated from the weather data, and its affects on garment wear were analyzed.

In the Body Armor Field Evaluation Program, the system being evaluated comprises the garment (which is resistant to penetration by a ballistic projectile), the officer wearing the garment, the total environment in which the officer is operating, and numerous ancillary factors which affect the officer's attitude and acceptance of protective garments. Because many of these factors can be neither controlled nor measured in an absolute sense, the test becomes quasi-experimental and the data become more subjective in terms of experimental responses. This imposes more stringent requirements in the design of the data gathering instruments, increased judgment when reviewing the data for completeness and adequacy of responses, and a greater reliance on sophisticated statistical tools for data manipulation and analysis.

The general procedure of analysis to be employed in analyzing the data is determined from the goals and objectives of the test program and by the nature of the data available for analysis. In particular, the assumptions that can be made correctly about the distribution of the data dictates which of two general classes of statistical test procedures--parametric or nonparametric--will be employed.

Nonparametric tests, which are also called distribution-free tests, do not require assumptions regarding the probability distributions from which the data are drawn. They are, therefore, applicable in any situation where the sample values are independent, which is a fundamental requirement for statistical inference from sample data.

Parametric tests use a model based on an assumed distribution of the population being tested and usually make assumptions about the parameters of the population. Parametric tests are more powerful (i.e., they require less data) than the corresponding nonparametric tests because they take advantage of the additional information of the distributional shape. However, if the assumptions are not satisfied, the question of comparative efficiency is irrelevant, as only the nonparametric tests yield valid conclusions.

In conducting tests in a relatively unknown environment, the conclusions based on parametric tests must be viewed with restraint until it can be demonstrated that the assumptions required for their use are satisfied. Because this was the situation encountered in this study, nonparametric techniques were employed almost exclusively in the analysis. The rest of this chapter presents the results of the analysis evaluating the stated goals and objectives.

B. Acceptability of Garments

The first goal to be addressed relates to the acceptability by the officers of the protective garments. The data summarized below relate to some of the more significant questions and parameters involved in this portion of the analysis.

The officers were asked to respond in terms of the level of protection they would find acceptable for a continuous wear garment. Sixty-five percent of the officers indicated that a garment would be effective if it protected against the impact of a .357 magnum or less. Approximately 26 percent of the officers indicated that an adequate level of protection would be that of a .38 special. Less than 10 percent felt that no protective garment was necessary. Since approximately 40 percent of the test group indicated a need for more protection than against the .38 special, this may have contributed to the lower than expected amount of wear.

On the pretest and posttest questionnaires, the test participants were asked questions concerning their ability to interact with the public in terms of six dimensions: relaxation, effectiveness, safety consciousness, public hostility, security, and self-confidence. At the start of the test, both the test and the control groups felt:

- o neutral in their relaxed feelings;
- o somewhat effective interacting with citizens;
- o somewhat safety conscious;
- o some hostility from the public;
- o somewhat secure; and
- o somewhat self-confident.

At the end of the test period, the control group did not alter its feelings with regard to these six items. The test group did not change their feelings with regard to relaxation, public hostility, or security. The data do indicate that the test group felt:

- slightly less effective in interacting with citizens;
- slightly less safety conscious; and
- slightly less self-confident.

The statement "A good police officer doesn't need to wear a protective vest to adequately protect himself in any situation" was posed to both groups. Both groups disagreed with the question both before and after the test. This would tend to support the hypothesis that the individual officers would accept and wear protective garments which met their individual standards of comfort and performance.

A set of 20 optional questions which are a version of Rokeach's Dogmatism Scale was included on the pretest and posttest questionnaires for both the test and control groups. The dogmatism scale was designed as a means of determining the degree to which individuals manifest a particular personality construct called dogmatism. These questions were posed to determine if the degree to which an officer reflects dogmatic characteristics is affected by wearing body armor. The answer was no; the data obtained showed no differences between the test and control groups at the start or the end of the test.

Each member of the test group was asked to respond to a pretest and posttest question in terms of the opinion of other officers to the garment. Initially, most of the test group felt that the attitude of other officers was one of indifference; this feeling did not change.

The remainder of this section is concerned with determining the acceptability of the garments by measuring the amount of time they were worn and the reasons given for their not being worn. First, data are presented on the undergarment styles--both the LEAA and commercial designs. Next, the results are presented on the women's garments. The integrated uniform jacket data are then shown. Finally, the reasons given by the officers for not wearing the garments are reviewed.

In addition to the three LEAA garments, four commercially available garments were selected. The characteristics of the commercial garments are as follows:

Garment Source	Coverage	Equivalent No. of Piles
A	Full wraparound upper torso	12
B	Front and rear panels only	14
C	Front and rear panels only	18
D	Front and rear panels only	24

Figure III-1 is a plot of the percent of time these seven garments were worn by calendar month. As shown in the figure, initially there was, a high proportion acceptance and wear of the garments. As the novelty wore off and the weather became warmer, the garments were worn less and less. The upward trend from August to December indicates the officers were willing to resume wearing the garments as the weather became cooler. A rough grouping of the garments shows the two garments with full, wraparound, protection were worn the most. The very heavy 24-ply garment was worn consistently less than any of the other garments. The remainder of the garments generated statistics that fell between these two.

In order to evaluate the affect that temperature and humidity had upon the frequency with which a garment was worn, NOAA weather data were obtained for the 15 test cities, and the Temperature Humidity Index (THI) was computed. The THI is used by the U.S. Weather Bureau as a measure

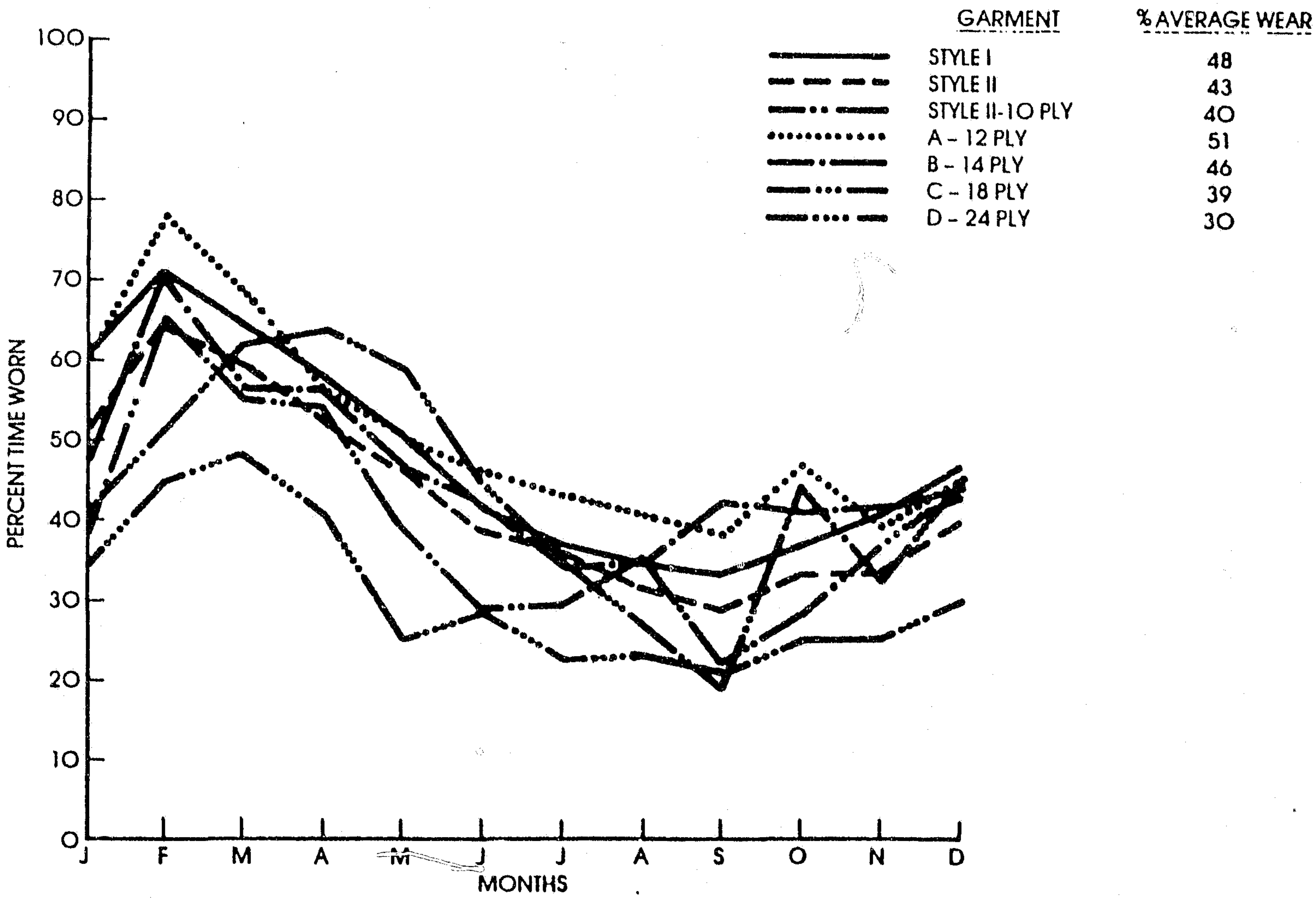

Figure III-1. Garment Wear vs. Month

of the degree of environmental discomfort. At indices below 70, few people experience discomfort. Values between 70 and 80 represent a transition period in which the sensation of discomfort increases with the index. At values above 80, discomfort becomes acute. As shown in Figure III-2, there was a rapid rate of decrease in the time a garment was worn for indices between 70 and 80. Again, the very heavy 24-ply garment was worn consistently less than any of the other garments.

A factor correlation with the percent of time a garment was worn was performed. The correlation coefficient of a factor with times worn may vary from -1.0 to 1.0. A coefficient close to 1.0 means that that particular factor varies directly with the time worn; a coefficient close to -1.0 means that the factor varies indirectly to time worn. Age has a coefficient of 0.38 which means that older officers tend to wear the garment more than young officers. Weight has a coefficient of -0.49 which means that the heavier officers tend to wear a garment less. A factor with a coefficient close to zero has no relationship to the time worn. The coefficients falling within the range of -0.1 to 0.1 are not considered significant.

The most significant factor was the THI, which had a negative correlation coefficient of -0.75 with wear. Other than THI, the most significant factors correlating with garment wear were garment comfort and freedom, officer age and weight, and characteristics of the officer's work area. A summary of the correlation coefficients of wear with these factors is given in Figure III-3.

In addition to the monthly wear data, members of the test group were asked (on the pretest and posttest questionnaires) how much they expected to wear and how much they actually wore the garments during the winter (cold) months and summer (warm) months. The average responses to these

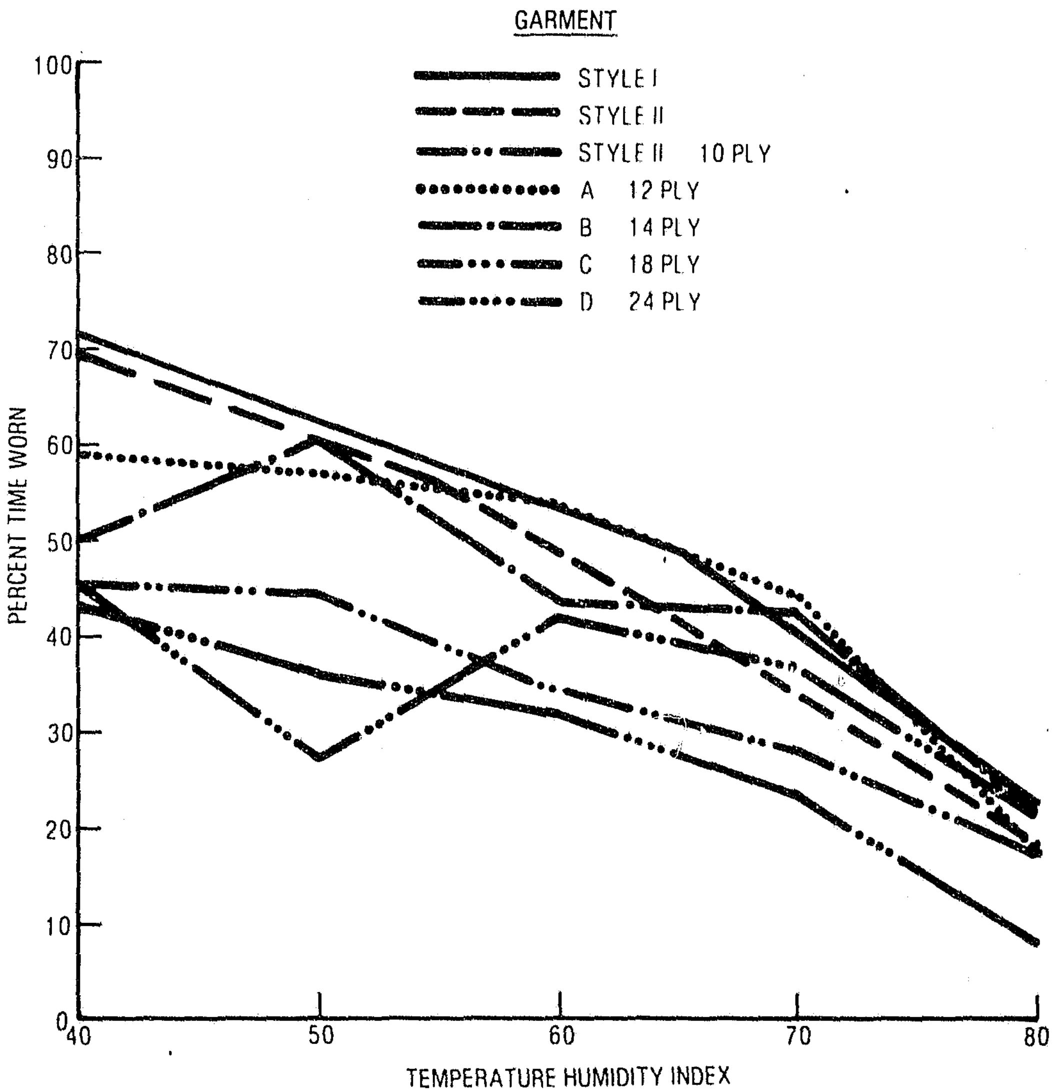

Figure III-2. Wear History vs. Temperature Humidity Index for All Undergarments

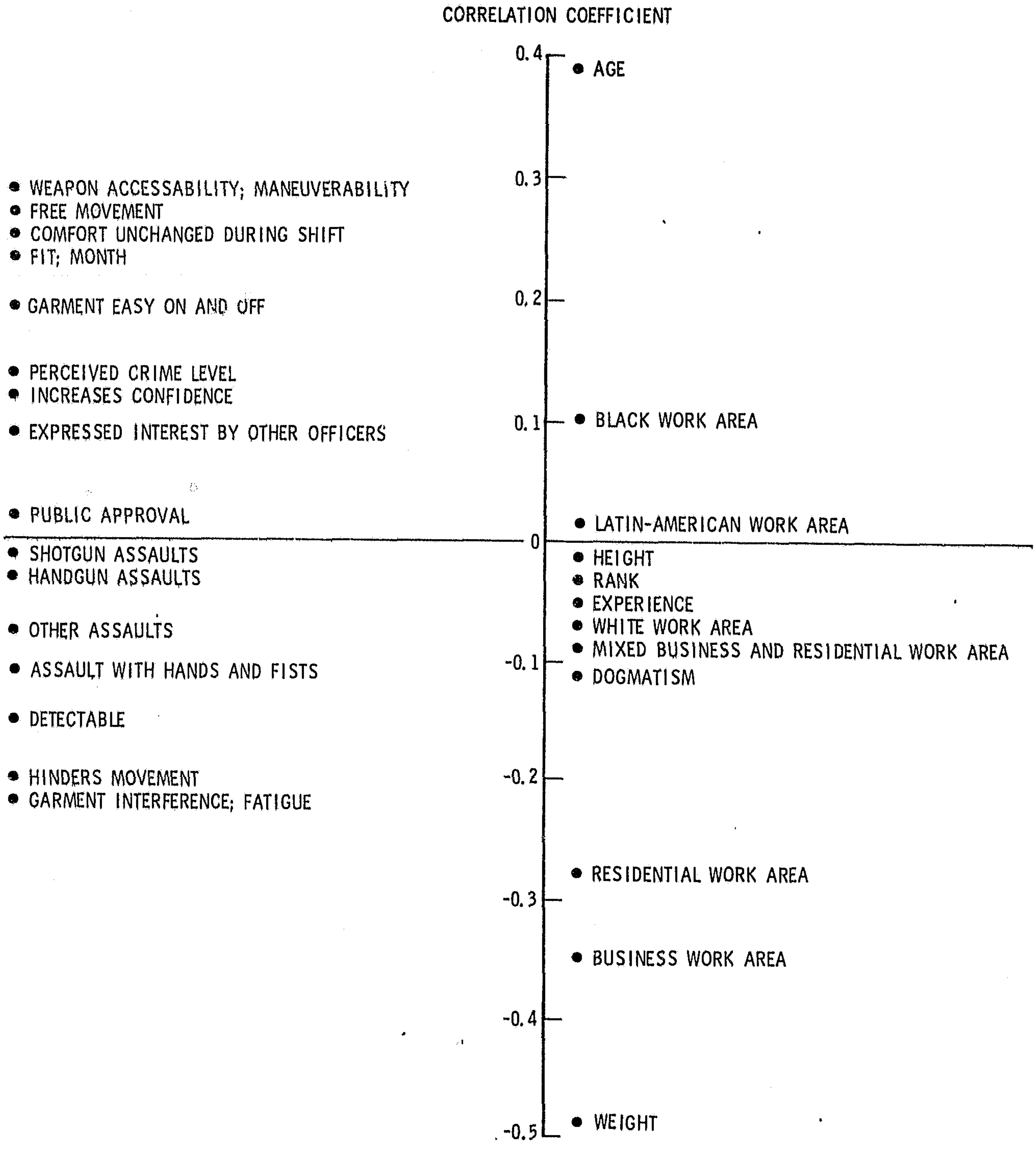

Figure III-3. Factor Correlation With Wear questions indicated that the officers anticipated wearing the garments. 73.4 percent in the winter and 65.2 percent in the summer months. Actual wear was 55.5 percent in the winter and 38.6 percent in the summer. These data support the observation that although there is a high degree of interest in obtaining protective garments, the observed wear is usually somewhat less than the expected wear.

The next set of results relates to the reported time of garment wear by the women officers. Initially, some women officers elected to wear the basic ballistic undergarment design for the male officers. In May 1976, 50 women's 7-ply and 50 women's 10-ply garments were distributed.

The questionnaire response from the test group wearing the LEAA women's 10-ply garments was not sufficient for valid intepretation of the data. For the LEAA women's 7-ply garments, the percent of time worn is shown in Figures III-4 and III-5. The wear history for the women's 7-ply garments is similar to that of the LEAA men's 7-ply garments except that the women show a greater sensitivity to THI with a marked decrease in the percent of time they wear their garments for THI's over 70 as opposed to the sloping decrease evidenced by men.

Two hundred fifty integrated uniform jackets were provided as part of the test program. The integrated uniform jackets were designed for wear during the cold months. The percent of time these garments were worn for the months of November through March is shown in Figure III-6. This figure shows that the garments were worn rather constantly (i.e., about 62 percent of the time).

Each month the officers were asked the major reason for not wearing the garment, and the data obtained from responses to this question were analyzed with respect to garment type. The most frequently reported

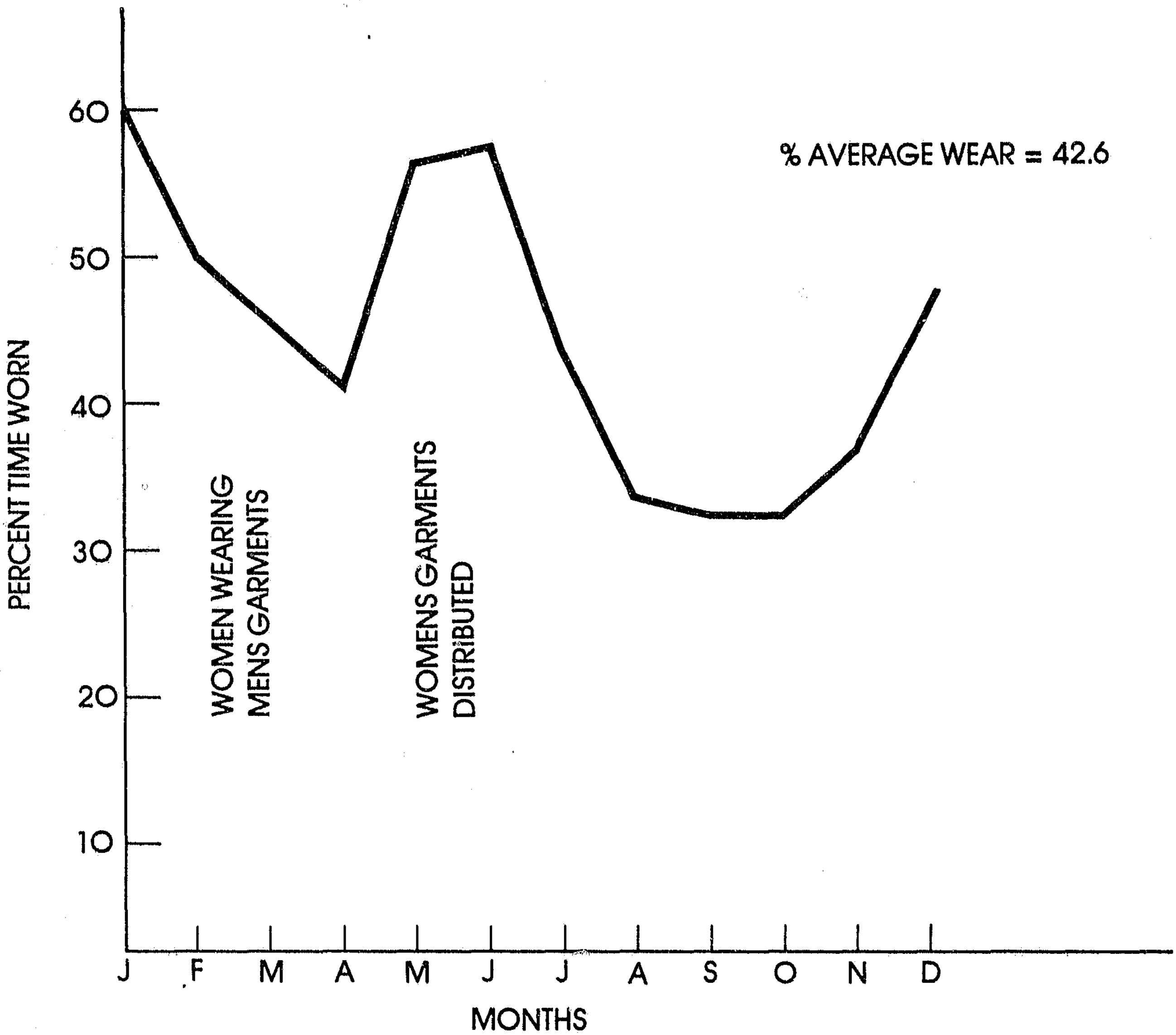

Figure III-4. Wear History vs. Month for LEAA Women's 7-Ply Garment

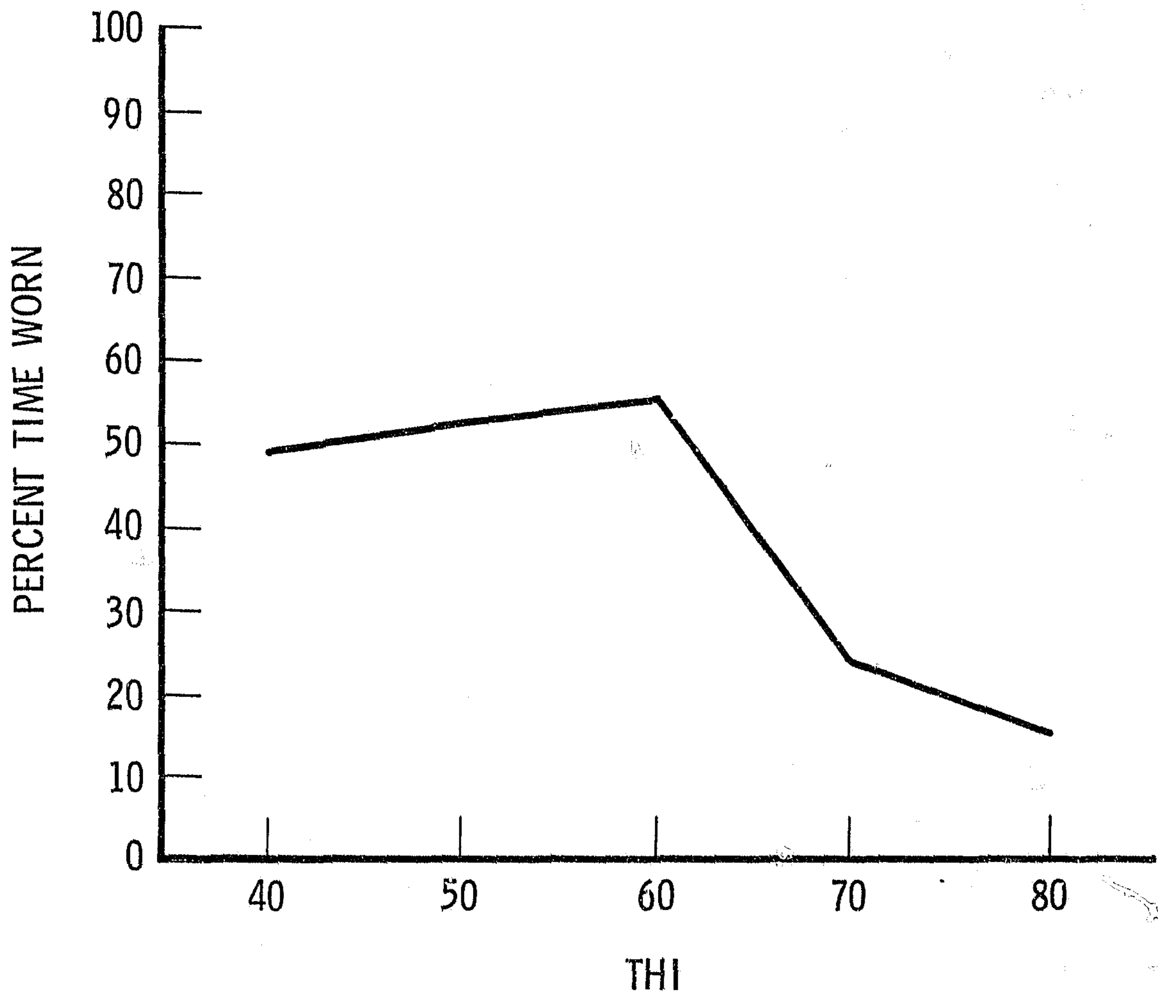

Figure III-5. Wear History vs. Temperature Humidity Index for LEAA Women's 7-Ply Garments

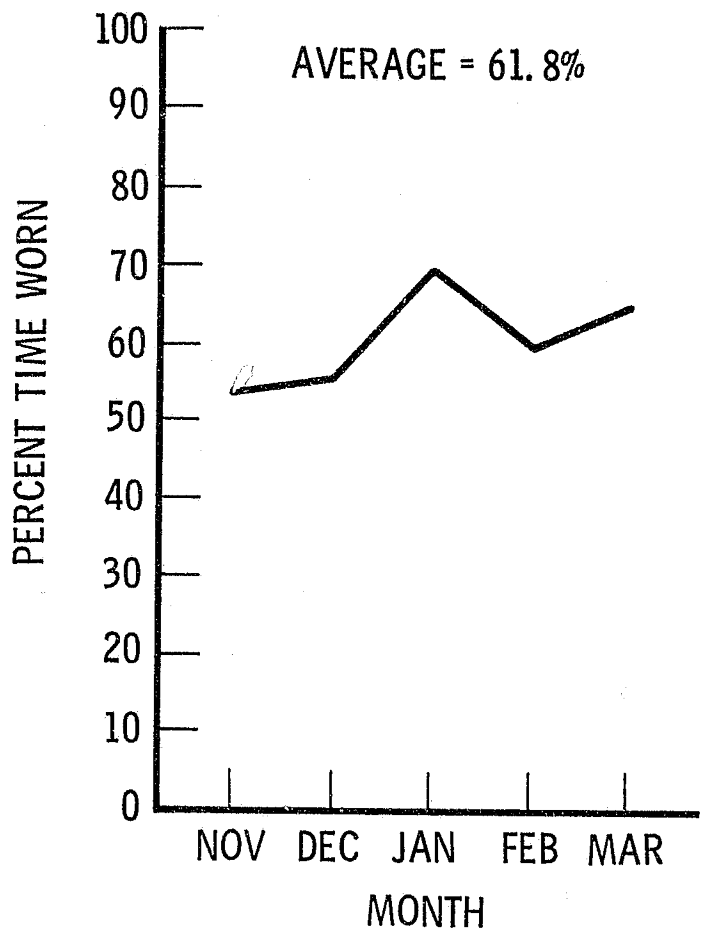

Figure III-6. Wear History vs. Winter Months for LEAA Integrated Jackets reason for not wearing a garment was that the garments were too hot (i.e., containment of heat was the most commonly reported negative factor for all garment types). Riding-up of garments was the second most frequent reason stated for not wearing the garments. Garment weight did not appear to be a significant problem except for Style D--protection level 24-ply commercial garment. The data on the garment binding is difficult to interpret. In general, the full or semi wraparound style caused more complaints than the front and rear panel only styles. The exception is again the very high protection level Style D.

On the monthly questionnaire for the test (wearer) group, each officer was asked to comment on the degree of discomfort experienced when wearing a protection garment by responding to the question:

> If you were to characterize any discomfort experienced in wearing the garment it would be:
>
> Rides up
> Chafes
> Contains heat
> Binds
> Heavy
> Cumbersome

For each characterization, the officer indicated the degree: very serious - cannot wear, serious - prevents wear for more than 2 hours, moderate - prevents wear for full shift, slight - noticeable, or irritating only.

The data obtained in response to the question were also analyzed with respect to garment type. There were no substantive differences found among the garments. Better than 50 percent of the responses were in the "irritating only" and "slight - noticeable" ranges for each of the areas listed above except the "contains heat" category. For this category, the discomfort becomes moderate and prevents the wearing of a garment for a full shift. This correlates well with the results reported from the data on the major reasons for not wearing the garments.

C. Performance of Garment

Garment performance includes the physical requirements of undetectability, fit, structural integrity, and ballistic protection. As a part of this study, we analyzed data in order to evaluate garment performance. On the monthly questionnaire (for wearers), the test group was asked to respond to the following statement:

> Frequent comments by the public indicate that the garment is easily detected.

Analysis of the response data showed that there was no substantive difference among the various garment types in their detectability by the public with the average response for all garment types falling in the "neither agree nor disagree" category. In addition, the test participants were asked on the posttest questionnaire the degree to which they found the LEAA Style I and Style II garments inconspicuous. Most officers felt that the two garments did not differ in their degree of conspicuousness.

On the monthly questionnaire, the test group was asked to respond to the following six statements relating to garment comfort:

> The garment is easy to put on and take off.
> The garment fits well.
> The garment allows free movement.
> The garment allows easy access to my weapon.
> The garment allows normal maneuverability.
> The garment comfort remains the same throughout the shift.

Analysis of the responses showed that generally the officers exhibit positive attitudes toward all these questions except that the garment comfort does not remain the same throughout the shift. This latter result correlates well with other data, and it appears that heat containment is the primary reason that the garment does not remain comfortable.

General comfort and fit was ascertained from a pretest and posttest item directly addressing the issue for the test group officers. The posttest question was:

> From your experience in wearing the garment would you say the general comfort level was:
>
> Very comfortable
> Comfortable
> No change
> Slightly comfortable
> Very uncomfortable

On the pretest questionnaire, the question was phrased "What level of comfort do you anticipate" with the same five response categories.

At the start of the test, the officers felt that the garment would either be somewhat comfortable or not change its general comfort level. At the end of the test period, there was a significant change of opinion and most officers felt that the garments were slightly uncomfortable.

In order to determine the garment integrity, the test group officers were asked on the monthly questionnaire the following question:

> The garment showed wear as follows:
>
> Seams opening
> Fasteners working loose
> Buttons falling off
> Ballistic material bunching up
> Wear at crease location
> Wear at material edges
> Velcro does not hold well

Appearance deteriorating
None
Other

Less than 2 percent of the officers indicated they experienced bunching of ballistic material regardless of the type of garment worn, and hence this is not considered.a major problem.

The officers' responses to the garment integrity questions were not as conclusive as the responses to the ballistic material item. Approximately 5 percent of the officers indicated that the garment fasteners had a tendency to work loose. The occurrence was most often cited by officers who wore the LEAA Style II, 10-ply garment.

Again about 5 percent of the officers indicated a problem with fabric wear at the garment's creases. Approximately 9 percent of the officers wearing Commercial Style A (12-ply) and 13 percent wearing Style B (14-ply) reported problems with garment wear at the crease. Significantly, less than three percent of the officers wearing Commercial Styles C (18-ply) and D (24-ply) garment types experienced this problem.

Approximately 6 percent of the officers indicated they found problems with the Velcro. The incidence of Velcro-related problems was generally consistent for all garment types, except Commercial Style C (18-ply). Only 1.4 percent of the officers testing Commercial Style C (18-ply) garment noted a Velcro problem.

Relative to concern about garment appearance, about 1 percent of all officers reported that the garment appearance was deteriorating. Three percent of this group were those officers wearing Commercial Styles A (12-ply), B (14-ply), and D (24-ply) garments.

In general, it can be said that the garments retained much of their structural integrity.

D. Impact of Garments

This section contains the results of an investigation of the possible overt and covert changes in officer attitudes or performance which may have resulted from wearing the garments and consequently impacted upon law enforcement operations. These changes are defined in terms of four measurement questions. The items associated with each measurement question as well as the results of the analysis of the responses to each item are discussed below.

A major issue surrounding protective apparel is whether or not the garment tends to make the officer more aggressive toward the public. This issue was addressed on the pretest and posttest questionnaires for both the test and control groups:

> Do you feel that while wearing the garment you were (would be) more or less aggressive as an officer?

Within the test group, 89.3 percent of the officers responded in the pretest questionnaire that there would be no change in aggression, and 85.9 percent responded this way in the posttest questionnaire. For the control group, 89.5 percent responded that there would be no change in the pretest questionnaire, and 83.5 percent responded the same way in the posttest questionnaire. From these data, it appears that there has not been a significant change in the officers' opinions before and after the test and that most of the officers feel that the aggressive behavior of police officers is not dependent upon the wearing of protective garments.

The next measurement item used to define officer aggression is composed of four sub-items. The collection of four sub-items attempts to determine the number of times the officer experiences a violent confrontation while in the line of duty. The appropriate pretest question is repeated below for convenience.

> Approximately how many times have you been assaulted in the line of duty since January 1972 (Violence or threat of violence), using:
>
> Handguns
> Shotguns and rifles
> Other dangerous weapons
> Hands, arms, fists, etc.

The associated posttest question used for comparison is repeated below:

> Approximately how many times have you been assaulted in the line of duty during the test period? (violence or threat of violence)

This question was posed to both the test group and control groups.

Analysis of the data showed that there was no significant differences in the proportion of officers in the test and control groups, either pretest or posttest, who experienced assaults in the shotguns and rifles or other dangerous weapons categories. There exists a very small amount of evidence which seems to indicate that protective garments may reduce the number of assaults experienced by an officer in handguns and hands, fists, etc. categories by an extremely small and, perhaps, nonmeaningful amount. A conservative inference would be that there exists evidence which indicates that the wearing of a protective garment does not have an impact upon the number of assaults experienced by a police officer.

On the monthly questionnaire, the members of the test group were asked to respond to the following three statements relating to the degree that the garments interfere with their performance of their duties:

> The garment hinders my movements while pursuing a suspect.
> The garment hinders my efforts to subdue an adversary.
> The garment interferes with my efforts during a rescue operation.

Less than 23 percent of the officers agree strongly or agree that garments hinder pursuing a suspect, less than 16 percent that a garment hinders subduing an adversary, and less than 15 percent that a garment interferes during a rescue. These responses were stable over time and indicate that most officers felt that the garments did not interfere with the performance of their duties.

Each month, members of the test group were asked if the garment increased their fatigue while on duty. The data showed that approximately 25 percent of the test group felt that the garment did increase, to some extent, their fatigue on duty. There is no significant trend in the data with respect to time, but there appears to be a slight increase during the summer months in the number of officers who feel that the garments increase fatigue. Thus the perceived increase in fatigue may be associated with the garment heat containment discomfort already discussed.

CHAPTER IV. SUPPLEMENTAL TEST AND ANALYSES

A. Recall Garments

The test plan required the periodic recall of garments from the field to monitor their performance for degradation. The garments to be recalled were chosen on the basis of frequency of laundering and amount of time worn. Recalled garments were replaced with new garments in the same size and style. The test program was established to determine changes in penetration resistance to the .22 caliber projectile, changes in the clay cavity from the .38 caliber projectile, changes in the tensile strength in the warp and fill directions, mechanical damage to the fabric fibers, and degradation in the Zepel-D water repellant treatment.

The rear panel of the recalled garments was used for ballistic testing. Three .38 caliber impacts were made on each panel to obtain average clay cavity measurements. The rear panel was then impacted with 10 well separated .22 caliber impacts to determine penetration velocities. The front panel was used for tensile specimens in both the warp and fill directions. Four samples each were taken from each ply in the warp and the fill directions. Remaining portions of the rear panel were used for microscopic examination and water break testing.

1. Tensile tests. The tensile tests were performed on the Instron Test Equipment from February to August 1977 after 9 to 18 months of wear. The average tensile values in the warp and fill direction are somewhat lower than the values measured during the acceptance testing of the production fabric. The acceptance testing showed fabric warp strengths between 1000 and 1300 pounds. The warp strength of the samples generally lay between 900 and 1200 pounds. Only one garment was significantly lower than these limits, but there did not appear to be a degradation in its ballistic performance. Similarly, the fabric acceptance testing showed fill breaking

strengths between 1300 and 1500 pounds. The test specimens from the recalled garments showed breaking strengths between 1100 and 1400 pounds. Again only one garment was significantly outside these limits and, again, this garment performed well in ballistic tests.

The degradation of mechanical properties did not appear to be reflected in loss of ballistic resistance. In investigating mechanical properties on a layer-by-layer basis, it was found the innermost layer (the one toward the body) showed the largest amount of strength loss. This would tend to draw the average tensile strength down but would contribute the least to ballistic penetration degradation.

2. Ballistic testing. The ballistic testing of the garments recalled from the field included using both .22 caliber and .38 caliber weapons. The .22 caliber tests were performed to determine penetration resistance, and the .38 caliber tests were performed to check the back face signature.

Seven plies of new Kevlar fabric yields a nominal depth of cavity in plastilina clay of approximately 1.8 inch (4.6 cm) with the .38 caliber 158 grain (gr) round-nose lead projectile moving at approximately 800 feet per second (fps). For the first set tested, the mean penetration depth was 1.473 inches with a standard deviation of 0.185 inches. In all the tests, the velocities were greater than 800 fps with two exceptions, an impact at 789 fps and one at 742 fps. There is apparently no significant increase in cavity depth for the garments tested. The second (later) set of tests yielded slightly larger and deeper cavities than the first set. Mean depth here was 1.712 inches with a standard diviation of 0.106 inches. This could be due to either the garment's becoming more flexible with use or the plastilina clay's being somewhat warmer and therefore softer for the second set of tests. Either way, the cavities are still reasonably consistent with those measured with new Kevlar panels.

The .22 caliber ballistic testing consisted of two sets from the earlier and later recall programs. The mean penetration velocity of the first set was 1073 fps and for the second set was 1097 fps. These valuse are consistent with those measured on the new Zepel-D treated material as shown in Figure IV-1. The ballistic resistance of the Kevlar fabric does not appear to be seriously degraded with wear and age, at least up to 18 months.

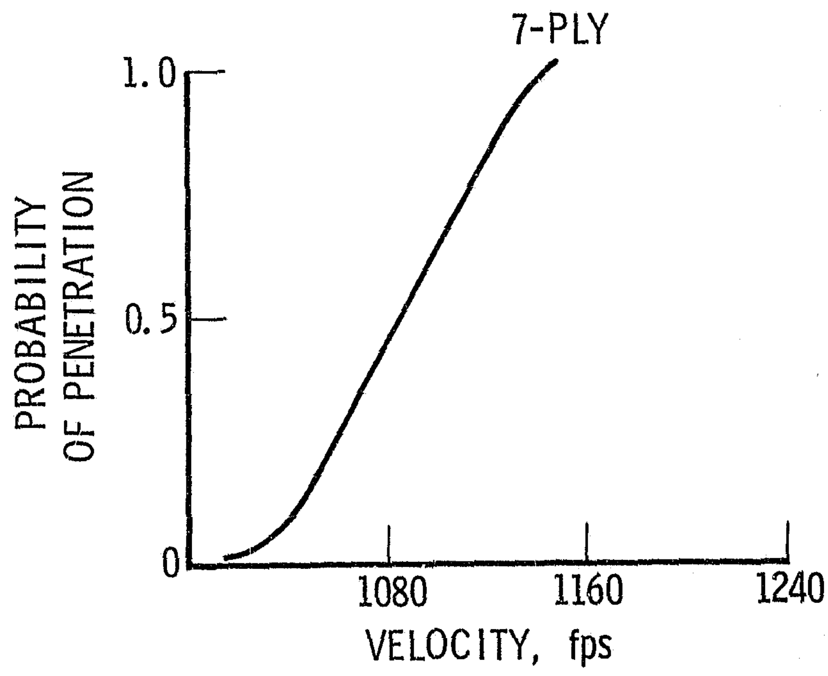

Figure IV-1. Typical .22 Caliber Penetration Probability for 7-Ply, 1000-Denier Kevlar

B. New Materials Testing

1. Ballistic tests. A review of the threat data, the availability of high-velocity .22 caliber ammunition almost to the exclusion of the standard velocity rounds, and the Police Foundation Report findings that there is a general upgrading of handguns on the streets, led to a reassessment of the .22 caliber projectile velocity. A review of available data and earlier experience in ballistic testing of .22 caliber revolvers indicated that the design velocity for the common handgun (i.e., .22 caliber) threat should probably be in the 1080- to 1100-fps rather than the 1000-fps range as originally specified. In view of this, a test series was undertaken to obtain the probability of penetration versus velocity for both 8 and 9 plies of Kevlar fabric.

Samples of 1000-denier 31 x 31 plain-weave Kevlar were purchased from five manufacturers of the woven fabric, and ballistic tests were performed on all samples to determine if major differences existed among the manufacturers and what the probable penetration velocities of .22 caliber projectiles in 8- and 9-ply fabric would be. Only one 8-ply sample performed poorly. The remaining samples performed similarly with some minor variations. Figures IV-2 and IV-3 show the ballistic test results for the 8- and 9-ply samples based on tests of all five samples of material. Figure IV-4 shows the penetration probability curves for 7-, 8-, and 9-ply samples for the .22 caliber projectiles with the test samples backed with clay.

C. High-Energy Threat Considerations

Concern has been expressed by most of the law enforcement community that there are more and more 9mm and .357 magnum weapons appearing on the streets and as threats against law enforcement personnel. In addition,

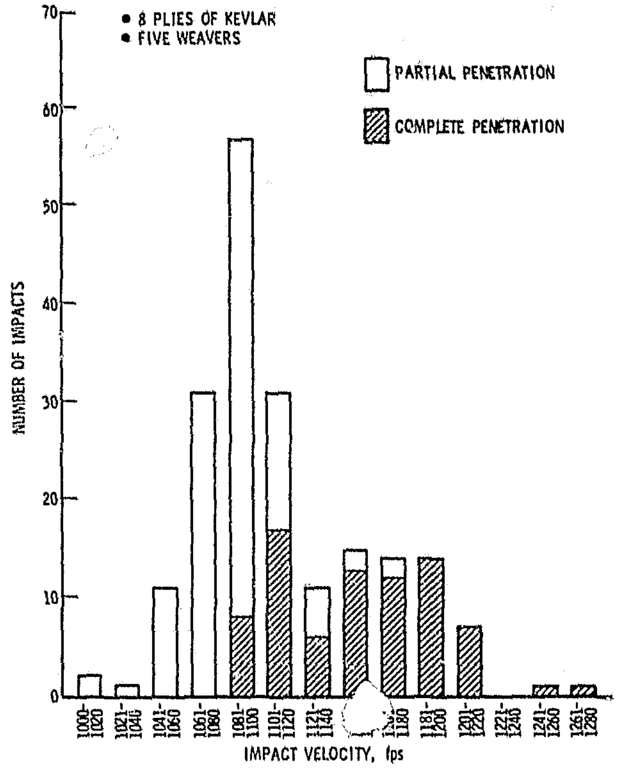

Figure IV-2. Ballistic Test Results for 8-Ply Kevlar

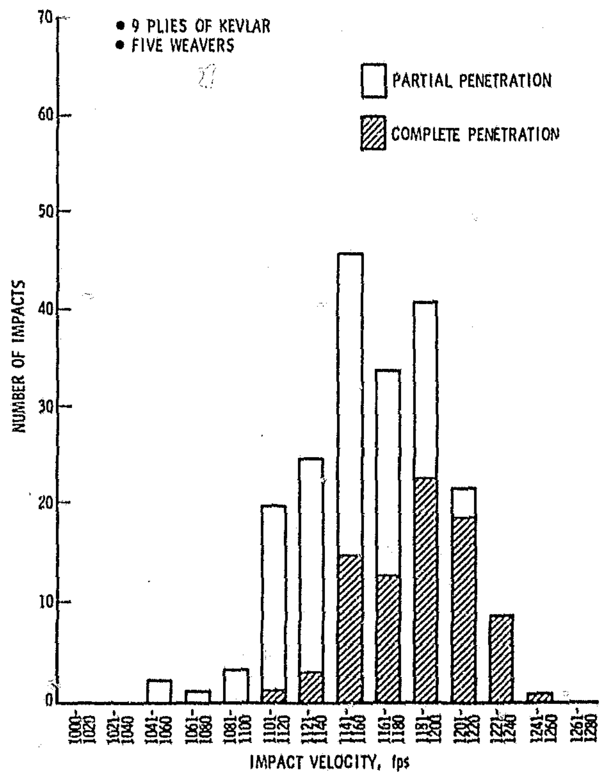

Figure IV-3. Ballistic Test Results for 9-Ply Kevlar

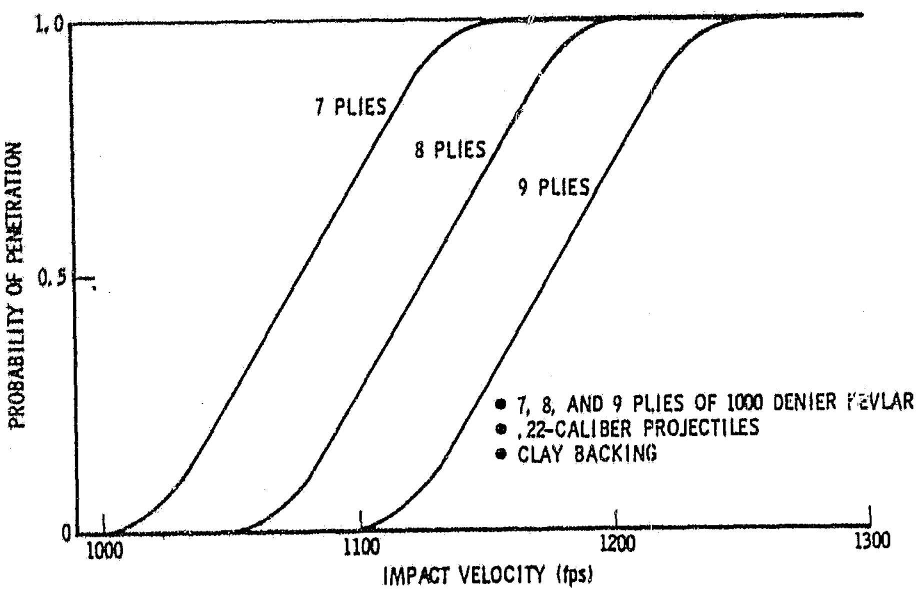

Figure IV-4. Probability of Penetration vs Velocity for 7-, 8-, and 9-Ply Kevlar

a number of municipal police departments have been specifying the .44 magnum as one of the threats required to be defeated by lightweight continuous wear armor. In an attempt to quantify the high-energy handgun threat, two short studies were undertaken. One was to obtain data on weapons confiscated by the police departments which were participating in the program in the years 1975 and 1976. The second was to review the law enforcement officer fatalities summary data from 1964 through 1976. Details of these two studies are contained in Appendix G of Volume III of this report.

These 1975-76 confiscated handgun data were compared with data from the 1971-72 study of the International Association of Chiefs of Police as shown in Figure IV-5. High-energy handguns comprise almost 10 percent of the 1975-76 data as opposed to 5 percent of the 1971-72 data. The greatest increase was in the .357 magnum weapons. Of the 18,500 handguns surveyed, only about 0.8 percent were a .41 magnum and .44 magnum weapons; therefore these weapons are not considered a significant threat.

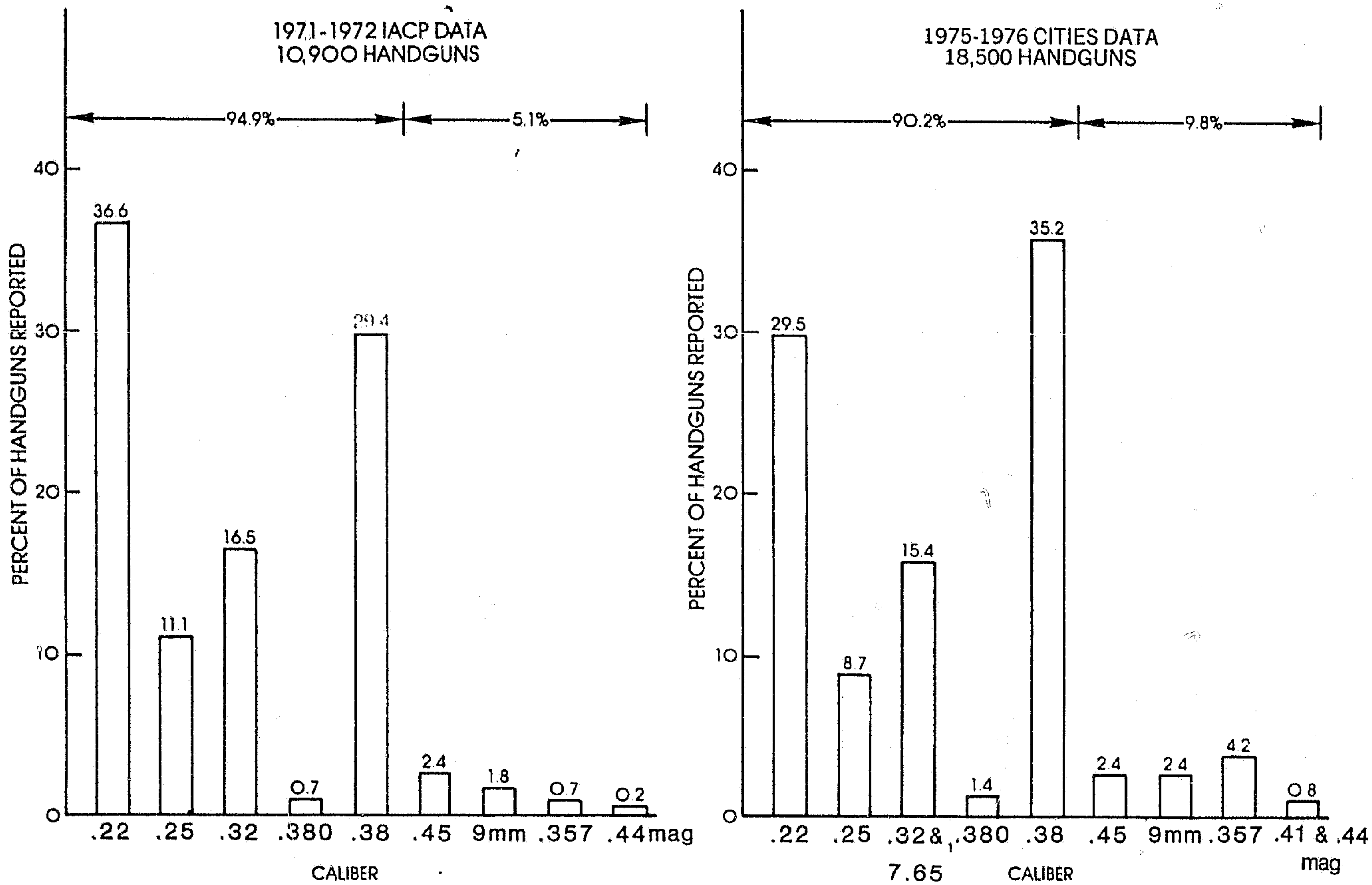

Figure IV-5. Confiscated Handguns--1971/72 and 1975/76

Figure IV-6 shows the history of law enforcement officer fatalities caused by handguns. Since 1970, there has been a steadily increasing percentage of fatalities from the higher energy weapons. In 1976, almost 30 percent of the fatalities were from high-energy firearms. A detailed review of the data indicates that of the total of 874 handgun fatalities, only six involved the use of .41 magnum or .44 magnum weapons. Three of these were inflicted by the officers' own weapons. Again, this represents less than 1 percent of the fatalities, which further substantiates the position that these weapons are not a significant threat.

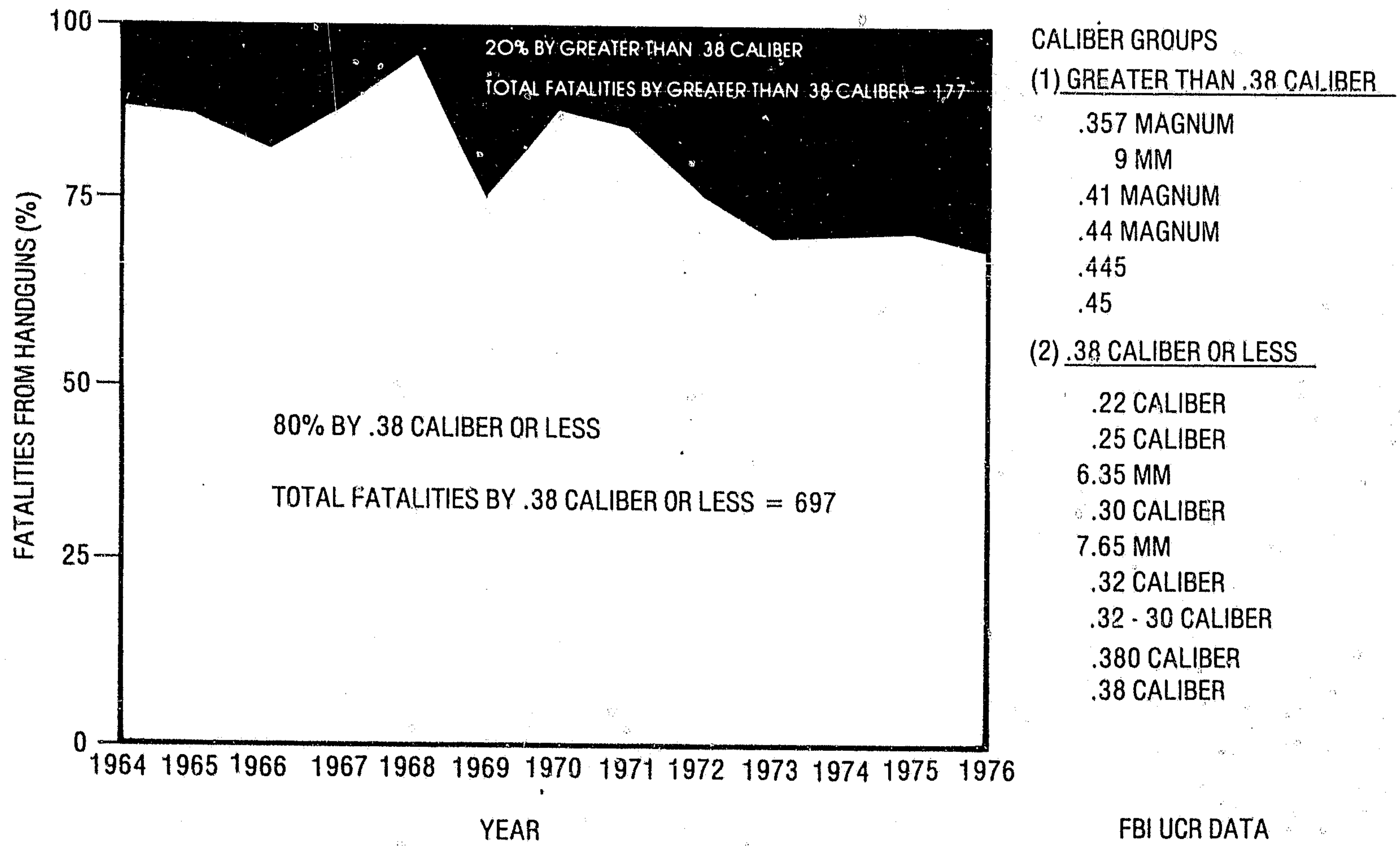

Figure IV-6. Officer Fatalities by Caliber of Handgun--1964-1976

CHAPTER V. MODEL PROCUREMENT SPECIFICATION

The Model Procurement Document, contained in Appendix B of Volume III of this report, is intended as a guideline only. It is provided to enable agencies intending to procure protective garments to have available the benefits of the configuration and design data developed from the Lightweight Body Armor Program.

The document is based on the protection level requirements which were established for the development portion of the program and the data and results obtained from the field test. As stated in the document, the garment design is intended to prevent penetration and serious injuries when impacted by projectiles from the common handguns.

The recommended garment configuration most nearly approaches the LEAA Style I garment employed in the test program. The major difference is that the garment is made up of three pieces--an outer carrier and front and rear ballistic material inserts--rather than integrated into a single unit. This configuration was employed primarily to eliminate the need to launder the Kevlar each time the carrier became dirty. Additionally, if two carriers are available, then one could be laundered while the second was being worn.

Other changes include the elimination of the buckles in the adjustment straps, increasing their width, and adding sufficient elastic in each strap to allow the garment to expand and contract with changes in body shape.

Full wraparound protection was retained because of one officer who sustained a wound in the side which would not have occurred had this feature existed in the garment being worn. Figure V-1 shows the recommended configuration of the Model Procurement Document specified garment.

An additional advantage to this type of construction is the ease with which the protection level may be increased or varied. By purchasing an additional set of inserts, in either 8-, 10-, or 12-ply construction,

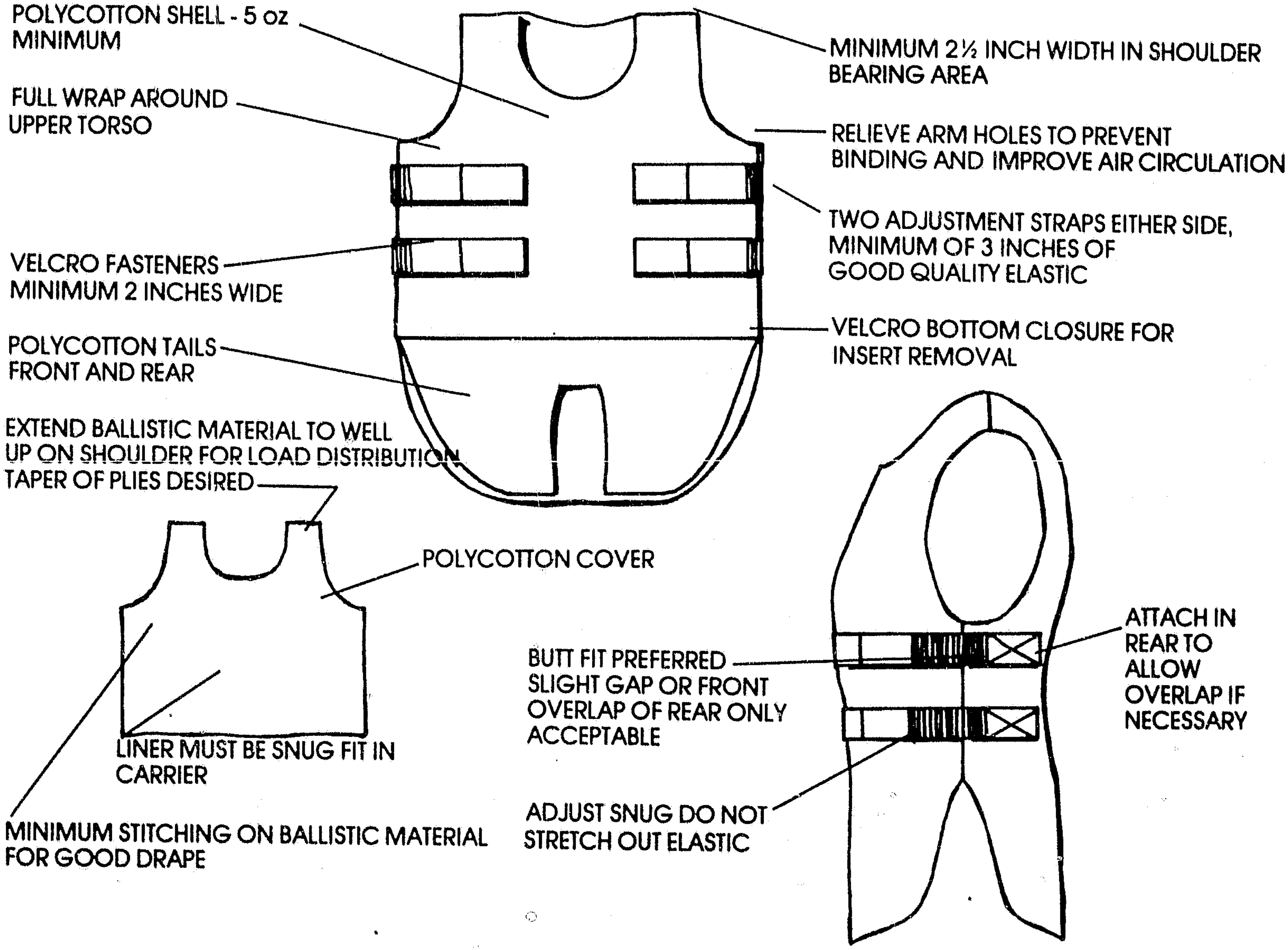

Figure V-1. Recommended Garment Configuration the garment can be upgraded to a higher threat level by installing two sets of inserts. By arrangement of the inserts, many combinations are possible, e.g., from a single 8-ply unit in the front with none in the rear, or up to two sets of inserts front and rear.

The Model Procurement Document identifies a ballistic test procedure. This may be replaced with NILECJ-STD-0101.01 when it is released. However, this standard will not contain a sampling schedule. The sampling schedule which is contained in the Model Procurement Document is based on MIL-STD-105 and should be retained.

The labeling information requirements should be treated as minimums. Additional information which may be required by individual departments should be added.

CHAPTER VI. KEVLAR CHARACTERIZATION

The two most important characteristics of the soft body armor are: (1) the ability to defeat the projectile and (2) the ability to spread the momentum of the projectile over a large enough region such that lethal trauma is not transmitted to the body. A considerable amount of experimental work has been directed toward measuring the penetration and trauma characteristics of the Kevlar 29 fabric. In particular, the 400/2 (34 x 34) Kevlar 29 fabric was thoroughly tested by Edgewood Arsenal, Lawrence Livermore Laboratories, and The Aerospace Corporation and is reported in Aerospace Report No. ATR-75(7506)-1. In addition, ballistic tests of the 1000 (31 x 31) Kevlar 29 material were conducted to verify its equal resistance to the .38 and .22 caliber handgun threats. In spite of all these efforts, little experimental information has been gathered to account for, or characterize, the ballistic performance of these fabrics versus areal density, or ply count. This chapter contains descriptions of two sets of empirical experiments conducted at Aerospace designed to supply this baseline information.

The completion of the lethality model by Edgewood Arsenal pointed out the fact that additional measurements of the momentum transfer properties of the Kevlar fabric were necessary. Edgewood Arsenal's lethality model correlates the probability of lethal trauma in man with the cavity formation in the Roma Plastilina No. 1 clay. Thus, a model that relates cavity formation to projectile momentum gives both the garment manufacturer and user a tool for assessing the adequacy of a particular armor and the practicality of attempting to defeat a given threat. Clay cavity measurements were carried out specifically to obtain the information necessary for utilizing the lethality model in this manner. Penetration tests were conducted under simplified conditions to provide a baseline for predicting penetration.

A. Clay Cavity Measurements

As a supplement to Edgewood Arsenal's lethality model, cavities formed in the Plastilina No. 1 clay behind 1000 denier (31 x 31) Zepel-D treated Kevlar 29 fabric of various ply counts were measured after having been impacted by the .22, .38 and .44 caliber lead projectiles at velocities between 400 and 1400 fps. (Testing was conducted at $70^{\circ} \pm 2^{\circ}$F.) Measurements of both the volume of the cavity and the increase in surface area of the clay due to the cavity were found to be described quite well by the two empirical relations:

$$\Delta S = \frac{1}{\sqrt{1 + n}} (8.6 m\gamma)^{1.35} \qquad \text{(VI-1)}$$

and

$$dV = \frac{1}{\sqrt{1 + n}} (5.0 m\gamma)^{2.14} \qquad \text{(VI-2)}$$

where:

ΔS is the increase in surface area of the clay due to the cavity in square inches,

n is the number of plies of Kevlar fabric,

m is the mass of the projectile in slugs,

γ is the velocity of the projectile in fps,

d is the depth of the cavity in inches, and

V is the volume of the cavity in cubic inches.

Test data plotted in Figures VI-1 and VI-2 show good conformance with these equations. These two relations also account for cavity data reported by Edgewood Arsenal, which included 400/2 denier (34 x 34) Kevlar 29 fabric, 1140 denier (27 x 27) Kevlar 29 fabric, and 9mm impacts.

It should be noted that this investigation was directed toward establishing baseline data on the 1000 denier (31 x 31) Kevlar 29 fabric. Fabrics of different weave configuration or having elastomeric coatings, in general,

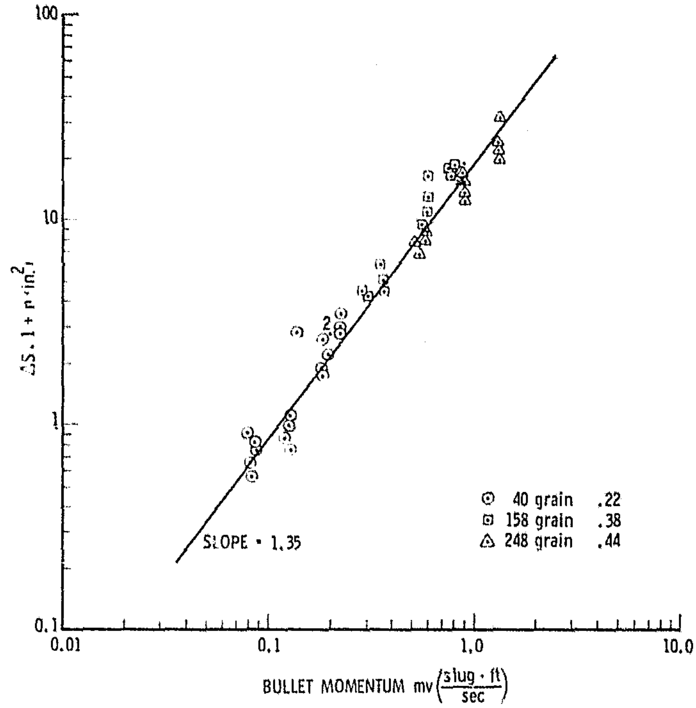

Figure IV-1. Change in Clay Cavity Surface Area vs Impact Momentum

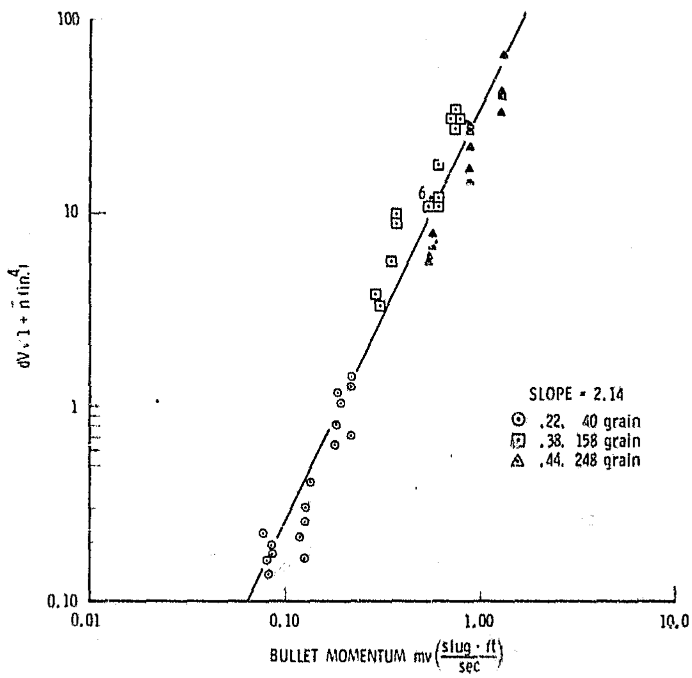

Figure VI-2. Change in Clay Cavity Volume Parameter vs Impact Parameter are not described by equations VI-1 and VI-2. However, these results establish a data base against which future developments may be assessed. Most importantly, this information may be used in conjunction with Edgewood Arsenal's lethality model for assessing the feasibility of protecting against the higher energy threats with conventional soft armor.

A cursory study of the effect of temperature on the behavior of the Roma Plastilina No. 1 clay was also made. Drop tests utilizing a steel cylinder having a hemispherical end for impacting the clay with constant kinetic energy were carried out at three different temperatures. The resulting cavity volumes indicate that cavity formation in this clay is extremely sensitive to its temperature. Thus, all experimentation involving measurements of clay cavity should carefully record temperatures. The clay cavity work presented here maintained $70^{\circ} \pm 2^{\circ}$F, which appears to be satisfactory.

B. Penetration Study

The penetration study was conducted in order to establish the baseline penetration characteristics of the 1000 denier (31 x 31) Zepel-D treated Kevlar 29 fabric. This investigation utilized air-backed specimens for several reasons. First, excluding the backing material greatly simplifies the interaction; not only is the overall experimental scatter reduced, but the test results may be directly related to projectile-fabric interaction. Second, exit velocities of the projectiles were desired; although use of clay or gelatin backing does not preclude the measurement of exit velocities, it introduces additional unknown variables and influences the backing material on the armor. Last, high-speed photography is much simpler without a backing material.

The most interesting result of the penetration study was the greater efficiency of the armor in the air-backed case. For instance, three plies of 1000 denier (31 x 31) Kevlar 29 fabric defeats the .22 caliber projectile at 1000 fps in the air-backed case, whereas 7 plies of this same fabric are required to defeat this threat when backed with clay. Apparently, the stresses resulting from bullet impact are better distributed when the rear surface of the fabric is not restrained. These results imply that improved penetration might be obtained by providing some sort of slip plane between the armor and backing material to provide for more uniform loading of the armor.

The most significant result of the penetration study is the linear relation obtained between the kinetic energy per cross sectional area of the projectile and armor thickness for each of the four projectiles studied: .22, .38, and .44 caliber lead projectiles and a 9mm full copper jacket projectile. This relationship is shown in Figure VI-3. The straight lines obtained for the .22, .38 and 9mm projectiles were nearly identical; the .44 caliber projectile exhibited a different slope. This result was quite surprising since one would expect the three lead, if any, projectiles to exhibit the similar slopes. The obvious extension of these results is to design a test matrix which would allow the slopes of these relations to be correlated with the physical parameters of the Kevlar fabric. Once correlated, the objective would be to adjust these parameters so as to improve the penetration characteristics of the fabric.

In conclusion, the baseline behavior of the momentum transfer and the penetration characteristics of the 1000 denier (31 x 31) Kevlar 29 fabric have been established. The information may be used to measure the relative improvements of new armor systems which are thought or claimed to

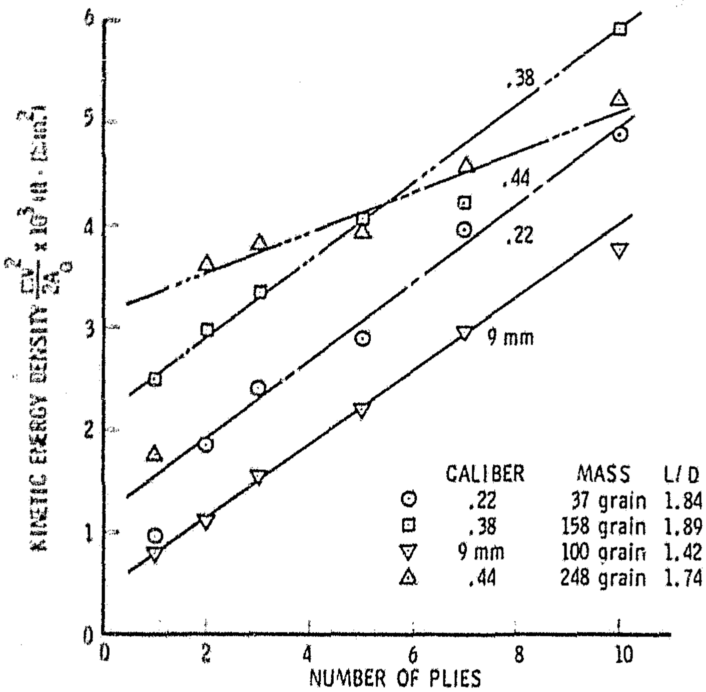

Figure VI-3. Kevlar Penetration Parameter vs Number of Plies

be superior. Additionally, these results suggest new areas of investigation. For instance, the greater stopping ability of the armor in the air-backed case certainly suggests an investigation directed toward determining the effects of friction-reducing agents between armor and backing and possibly between adjacent plies. The similarities in the penetration behavior of the .22 and .38 caliber and 9mm projectiles suggest that an expanded study should be made, which would include the European 9mm steel projectile in addition to a 9mm lead and 9mm FMJ lead projectiles. Because the slope of the kinetic energy density versus ply number is a measure of the case with which penetration occurs, these three 9mm projectiles would be expected to vary considerably. If not, the implication is that the intercept or the onset of penetration is related to projectile hardness.

CHAPTER VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The principal conclusions obtained from the Body Armor Field Test and Evaluation Program are summarized in this section. They are reported in accordance with the goals of the program as originally defined in the test plan published in June 1975.

1. Evaluate garment acceptability. The majority of the officers felt that an adequate level of protection would be that which would protect the officer from a projectile of an energy equivalent to a .357 magnum.

When interacting with the public, there was no change in the test participants in their feelings of relaxation, public hostility, security, fatalism, or dogmatism. The data did indicate that among the officers' who wore protective garments, there may have been a slight decrease in their feelings of effectiveness, safety consciousness, and self-confidence. The officers consistently felt that their peers were neutral (neither complimentary nor critical) in their feelings about someone wearing a protective garment.

The protective vests were worn between 30 and 50 percent of the time. The garments having the most plys were worn a lower percentage of the time then the lighter garments. In the cold months, the garments were worn an average of 55 percent of the time; in the warm months, they were worn an average of 38 percent of the time. This correlates well with the major reason that the garments were not worn (viz, because they were too hot). The integrated uniform jackets are appropriate for wear only during the winter months; during that period, they show a high level of use, being worn, on average, 62 percent of the time. For the most part, appearance seemed to have little or no effect on acceptability.

From the very beginning, the participating police departments strongly supported the test program. Only one of 16 departments approached declined to participate; that department did so on the basis of a prior decision to purchase garments for the entire department.

Subsequent to the start of the program, a significant number of municipal, county, state, and federal law enforcement agencies have purchased garments.

At the end of the field test, the participating departments were offered the option of retaining the garments. All 15 departments accepted.

2. Evaluate garment impact on law enforcement operations. There were no indications of any significant psychological change of the test group while wearing the protective garments. Concern was expressed by a number of law enforcement personnel that the wearing of the garments would induce a feeling of invincibility in the officers. The so called "superman" syndrome did not manifest itself either in the data or in the incidents which were investigated. There was some indication in the data that the officers wearing garments actually suffered proportionately fewer handgun assaults than the officers who were not issued garments.

A short series of dogmatism questions showed no change in dogmatic attitude during the test period in either the test group or the control group.

There were no indications that wearing the garments significantly degraded the ability of the officer to perform his assigned duties. About 25 percent of the test officers indicated some increase in fatigue while on duty because of wearing the garments.

The benefits of garment use to both the law enforcement agency and to the individual officer were estimated. The benefit of the individual is, of course, that it may possibly save his life. An evaluation of 1976 data involving body armor indicated that approximately 18 potential fatalities were avoided. Of these, two instances involved officers wearing garments provided by the program and the remaining 16 involved officers who were wearing commercial armors.

Based on the data obtained from a major police department on only the monetary losses associated with an officer fatally wounded, cost/benefit estimates were made of the departments purchasing armor. If a city which has approximately 3000 sworn officers purchases armor and as a result, one fatality is prevented in five years, then the city would break even. This assumes the average cost of an under garment is approximately $65. These calculations do not take into account the possible cost savings associated with any injuries that would be avoided. Nor do they take into account the other factors such as impact on the survivors, impact on officer morale, or police-community relations.

3. Evaluate garment performance. The majority of the data indicated that the garments were inconspicuous to the casual observer. As the garments become heavier and thicker, they tended to add an appearance of bulk to the officers wearing the garments. There did not appear to be a significant difference in the detectability between the Style I and Style II garments.

The factor which caused the most discomfort was the containment of heat. A most important factor for comfort is proper fit.

In both the Style I and Style II garments, there was very little elastic in the adjustment straps. Sufficient elastic should be provided to allow the garments to give with normal changes in body dimensions. Also, the officers should be instructed to adjust the garments without taking all the stretch out of the elastic. The lack of elastic in the adjustment straps and lack of tails on the Style II garment were the major causes for their riding up.

In general, the officers felt that the garments were easy to put on and take off, fit well, allowed free movement and easy access to their weapons, and also allowed normal maneuverability. The deterioration of the garments with wear during the 1-year test was minimal. There was a tendency for the ballistic material to pull out from the bias binding tape, which indicates that better shaping at the corners or wider tape is needed. The buckles of the Style I garment cut through the elastic tape to cause failures. Buckles should be eliminated, since they are a potential source of shrapnel. The Velcro fasteners tested held up well.

During the field test, 60 LEAA garments were recalled to determine if there was any change in penetration resistance, clay cavity depth, or fabric tensile strength in either warp or fill direction. The selected garments were those that were worn and laundered the most. The ballistic resistance of these garments was not degraded, nor was there any significant change in cavity depth or tensile strength.

Based on the incidents that occurred involving the 7-ply garments, all operational requirements were met with the exception of the desired 80-percent wear. The wear history was somewhat lower than expected and will require a breakthrough in heat rejection to gain a significant improvement. The recommended design changes should improve wear probability by increasing slightly the apparent comfort of the garments.

The protection afforded by the garments was entirely adequate. In the incidents that involved the 7-ply garments, there was no indication of any internal damage due to blunt trauma. The injuries that occurred were to the skin and comprised an abrasion-type contusion with some weeping of bloody fluid and a later developing bruise with discoloration. The contusion area was nominally 3/4 to 1 in. in diameter. The swelling and discoloration developed to 3 or 4 in. in diameter. On the basis of the limited data available, the U.S. Army predictions from the animal tests were too conservative.

4. Evaluate cost and feasibility of mass production. In fabricating both the undergarments and the integrated garments, once the design was established, there were no major problems in manufacturing. Good tailoring practices combined with commercial machines and qualified operators indicated no major difficulties in quantity production.

The best-estimate average cost for the LEAA-designed garments was approximately $60. These were the first quantity production and improved fabrication techniques may have resulted in lower costs had these techniques been available at that time. Inflation in both labor and material since 1975 have probably offset these potential savings.

The new recommended garment design, which includes the 8-ply insert and carrier configuration, has been estimated at $80 to $90 in lots of 10 units; $65 to $75 in lots of around 1000. Again, inflation will cause these estimates to increase after the date of this report.

B. Recommendations

The Body Armor Program has accomplished two rather difficult tasks. First, it met all goals and objectives. Second, it achieved technology transfer to both industry and the user, which is rare indeed. One result of this success is a rather clear and specific set of recommendations which fall naturally into two categories: additional research and guidance on the procurement and use of soft armor. Both groups of recommendations are based on the findings of the program.

1. Research and development. The results of the work just completed points the way to additional work that is needed. Based on the discussions held with the nation's major law enforcement agencies during the body armor briefings, the users recognize this need and fully support what is recommended. Industry representatives also support it. The point should be made that this work does not involve a question of feasibility. The results to date clearly indicate that further improvements in soft body armor can and should be made.

a. Almost all interested agencies asked for information on garment lifetime. The test program was limited to a 1-year period, during which time the garments remained relatively new. Since all of the test cities except one elected to retain the garments, an opportunity exists to obtain a better fix on wear characteristics and the lifetime of armor at relatively low cost. The program should be continued to recall and test the garments left with the participating cities. Emphasis should be placed on the penetration resistance to the .22 caliber projectile.

b. Research should be undertaken to define the protection level required to defeat the higher energy threat represented by .357 magnum and 9mm handgun projectiles. The .41 and .44 magnum should not be considered as design threats. The .357 magnum should be the 158 grain, semi-jacketed, soft nose bullet at approximately 1400 fps. The 9mm should be the 124 grain, full-metal jacketed bullet at approximately 1200 fps. This effort should evaluate the ability of new weaves of various deniers of Kevlar, both with and without coatings, as well as existing commercial fabrics, to defeat penetration and to control blunt trauma from these threats. Additional medical research should be undertaken to determine the potential lethality of internal injuries sustained from non-penetrating impacts of these projectiles.

c. An evaluation program should be conducted on the characteristics of commercially available, coated or impregnated, Kevlar. Coatings are frequently applied to Kevlar fabric to reduce deformation caused by impact, particularly that from high-energy weapons. The durability of these coatings and their effect on wearability should be tested. Emphasis should be placed on determining the useful life of coatings after calibrated exposure to various environmental agents (e.g., washing, dry cleaning, perspiration). Methods of garment construction and tailoring for maximum comfort should be explored.

2. Procurement and use of soft body armor. This section incorporates a selection of the most important considerations to be kept in mind when buying or using soft body armor. They are not directed towards a single type of garment, though it is limited to the undervest. Otherwise, the guidelines are generally applicable.

a. The ballistic certification of armor sold to law enforcement agencies should be provided by the vendor or by an independent agency. The certification should be based on tests conducted at a laboratory with proven and traceable standards for the chronograph, and with specified test procedures, particularly in the handling of clay for cavity measurement. The number of samples should follow the schedule of MIL Standard 105 for a quality assurance level of 0.25 percent.

b. The acceptance tests of the buyer should include a visual examination of each garment for defects in material or workmanship. Since proper fit is paramount, the size of each garment should be checked. User ballistic acceptance tests are optional. If the vendor certifies the ballistic performance, witnessing these tests is usually more cost effective than performing them over again.

c. The ballistic material should consist of Kevlar 29 woven from scoured yarn of a single merge. The fabric should be treated with Zepel-D, or equivalent, water repellant to avoid ballistic degradation from perspiration or other sources of water. If alternate water repellants are used, ballistic tests should be conducted to assure that the fabric maintains its ballistic resistance.

d. Since laundering of the test garments appears to cause mechanical damage due to the agitation in the washer and dryer, it is recommended that the basic garment design be changed to a carrier with a removable set of inserts.

e. The outer carrier of the garment should incorporate shirt tails front and rear to prevent riding up of the insets. Relief at the arm holes should be adequate to prevent binding and to improve air circulation. No metal (e.g., buckles) should be used in construction since this is a potential source of shrapnel. Velcro straps, two on each side, with a minimum of 3 in. of good quality elastic are recommended to ensure that additional stretch remains such that the garment flexes with body movement, particular breathing movement. The plies of ballistic inserts should not be stitched together, but only minimally tacked to maintain flexibility.

f. Fit is very important to wearability. Instructions should be given to each officer on the proper way to don the garment. The user should exercise care in specifying sizes to be produced to ensure that a proper size garment is issued to each officer. The fabricator must exercise care in tailoring to ensure proper fit and comfort.

CHAPTER VIII. BIBLIOGRAPHY

A Method for Soft Body Armor Evaluation: Medical Assessments, Dept. of the Army, Edgewood Arsenal Report EB-TR-74073, January 1975.

An Evaluation of Police Handgun Ammunition, Summary Report, National Bureau of Standards, Law Enforcement Standards Laboratory, LESP-RPT-0101.01, October 1975.

Body Armor Blunt Trauma Data, National Institute of Law Enforcement and Criminal Justice, Department of Justice, Report No. EB-TR-75016, May 1976.

Body Armor Field Evaluation, Test and Evaluation Plan, Aerospace Report No. ATR-75(7921)-1, June 1975.

Body Armor Processing and Evaluation, Final Report (Vol. I - Executive Summary, Vol. II - Technical Report, Vol. III - Appendices), Laboratory for Statistical and Policy Research, Boston College, July 1977.

Body Armor Program Briefings, Aerospace Report No. ATR-77(7921)-1 (Vol. I - Executive Summary, Vol. II - Background and Test Results, Vol. III - Model Procurement Document), July - August 1977.

Lightweight Body Armor for Law Enforcement Officers, Dept. of the Army, Edgewood Arsenal Special Report EB-SR-75001, March 1975.

Miller, M. J., Jr. and Boyd, G. W., "Ballistic Protective Device for Law Enforcement, An Historical and Contemporary View," The Police Chief, Vol. XLIV, No. 10, October 1977.

Protective Armor Development Program, Final Report, Aerospace Report No. ATR-75(7906)-1 (Vol. I - Executive Summary, Vol. II - Technical Discussion, Vol. III - Appendices), December 1974.

END